# SURGICAL TREATMENT

## BANCROFT
## AND PILCHER

# *NERVOUS SYSTEM*

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# SURGICAL TREATMENT

## OF THE

# NERVOUS SYSTEM

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*With 293 Illustrations and 5 Color Plates*

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*Cranial and Intracranial Surgery, Tumors, Epilepsy and Cranial Nerve Disorders,
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# Preface

The surgery of the nervous system, more than most other special fields of surgery, demands a highly specialized technic and a diversified fund of knowledge and experience, but it is true that the general surgeon must frequently face the necessity of handling neurosurgical problems (particularly in the traumatic field). It is also true that an authoritative work on operative neurosurgery may be of value to the neurosurgeon.

In no other single volume will be found the assembled opinions of so many different competent authorities on the various problems of neurosurgery. Each author has approached his subject in his own way and any attempt at standardization of the various chapters has been deliberately avoided. Such a treatment of the subject affords not only highly authoritative opinion on individual subjects, but a healthy diversification of opinion on neurosurgical problems as a whole.

From these opinions of his fellow authors, the editor of this volume has learned so much that he has no hesitation in predicting that others will profit equally from them.

There is no place in the body of this book for a discussion of the making of a neurosurgeon, nor should this subject claim much space in this preface. It may not be amiss, however, to emphasize that the vast body of knowledge represented and the innumerable special technical methods described in these pages point inevitably to the absolute necessity for long, diversified, and highly specialized training for him who wishes to be worthy of the name "neurosurgeon." And it may be hoped that this volume will serve as a warning to those who, with little such background, but perhaps with some experience in traumatic or military neurosurgery, may be tempted to plunge into this difficult and exacting field of surgical endeavor too hastily.

In order to avoid repetition, the first chapter on "General Principles of Neurosurgical Technic" was prepared. This represents the opinions of a single individual and it is natural that some differences are reflected in the chapters by other authors. It is significant, however, on perusal of the various chapters, to observe how little variation there is regarding the fundamental principles of neurosurgical technic. Through the pages of this volume, the invisible hand of Harvey Cushing makes known its omnipresent influence.

During the stages of the preparation of this volume, revolutionary advances in the treatment of infections of the nervous system have occurred. It has been thought best to include a chapter on chemotherapy rather than to risk confusing disruption of the several chapters in which this subject arises.

Arbitrary division of the wide field of neurosurgery into various subdivisions could never be ideal. Some overlapping must necessarily occur and some omissions are no doubt inevitable.

The brief reference lists appended to the various chapters are designed not for bibliographic completeness, but rather to give the reader a route of approach to the respective subjects or to add weight to opinions expressed by the authors.

The editor of the volume wishes to express his deep gratitude to the other authors whose knowledge, experience, industry, and unfailing cooperation have made this volume possible.

He is also profoundly appreciative of the thoughtfulness, tolerance, and patient assistance of Mr. E. W. Bacon and Mr. Walter Kahoe of the J. B. Lippincott Company.

C. P.

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# CRANIAL AND INTRACRANIAL SURGERY

CONGENITAL, TRAUMATIC AND INFLAMMATORY DISORDERS

# 1

# General Principles of Neurosurgical Technic

## Cobb Pilcher, M.D.

## INTRODUCTION

In subsequent chapters will be found the consideration of the surgery of the various disorders and lesions which constitute the field of neurosurgery. The present chapter is concerned with the general principles of neurosurgical technic, applicable alike to most or all of the operative problems of neurosurgery. It is in these technical principles, and in the knowledge and experience with which they are applied, that neurosurgery differs from other fields of surgery.

## TECHNICAL CONSIDERATIONS*

Preoperative Care. The presence of increased intracranial pressure in many cases introduces certain special considerations. The condition of the patient may change with great rapidity, and careful observation and accurate recording of pertinent information (such as blood pressure, pulse rate, respirations, and the pattern of convulsions) are frequently essential.

In the presence of increased intracranial pressure, morphine should never be given as a routine ward measure, for it depresses the already compressed respiratory center. Acetylsalicylic acid and codeine are usually adequate analgesics, phenobarbital and dilantin are the best anticonvulsant drugs,

and paraldehyde and chloral hydrate help best to control the delirious patient.

The skin, mouth, eyes, and bladder of the unconscious or irrational patient must receive meticulous care. Constipation must be avoided, for straining at stool increases intracranial pressure. Enemas are preferable to cathartics.

For immediate preoperative preparation, an enema should be given. If a rectal anesthetic is planned, the enema should precede the operation by at least eight hours. A small dose of morphine or sodium amytal may be given. In the author's opinion, no preliminary medication whatever is preferable.

The head should be shaved immediately prior to operation. A prolonged interval after shaving provides opportunity for infection of the innumerable tiny abrasions of the scalp and hence increases the risk of a serious postoperative wound infection.

Anesthesia. The appropriate anesthetic will necessarily vary with the individual patient and with the preference of the surgeon. In most rational and unexcitable adults, local infiltration with 0.5 per cent procaine, containing 3 minims of epinephrine per ounce, is probably the anesthetic of choice.

If general anesthesia is desired, the anesthetic of choice is still ether, preferably administered by the endotracheal method. This provides smooth anesthesia, ready

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* In addition to the principles discussed in this chapter, certain special considerations in surgery of the spinal cord and of peripheral and sympathetic nerves will be discussed in their respective chapters.

suction of respiratory secretions, and an available means of prompt artificial respiration, if necessary.

Avertin (tribromethanol with amylene hydrate), administered by rectum, and supplemented by local infiltration with procaine, is often very satisfactory and its use avoids some of the unpleasant features of inhalation anesthetics. It should be regarded as a "basal anesthetic" and not as an agent for producing a deep anesthesia.

Individuals vary greatly in their response to avertin. In general, the older the patient, the smaller the necessary dose. Quite frequently, avertin will prove inadequate and will result in a state of irrational restlessness, requiring additional anesthesia. In such cases, ether is the preferable agent.

Small children respond poorly to avertin and it is usually best simply to give them ether by the open-drop method.

For some procedures, many surgeons prefer pentothal sodium, administered intravenously. An excellent apparatus for maintaining uniform injection of this drug has been devised by Rudder.

Equipment. Because of the several special devices required, the operating-room set-up must be carefully planned. The table should be high and the members of the team should stand on footstools. This provides adequate height for the anesthetist beneath the draperies and keeps the surgeon from standing on a wet and perhaps slippery floor.

Apparatus which must be suitably arranged includes the electrosurgical unit, a high-vacuum suction apparatus, and a motor-driven drill. A satisfactory arrangement of the operating room is shown in Fig. 1 (above) and the usual positions of the patient in Fig. 1 (below).

Many types of operating-room lights are employed, but the surgeon usually falls back on a headlight and often on electrically lighted retractors. The headlight should be of a type which produces very little heat, for the surgeon's head is necessarily close to the exposed brain.

Instruments need not be listed in detail here. Elaborate equipment is, of course, necessary, and special instruments will be mentioned in the descriptions of the various operative procedures.

Operative Approaches. In planning the exposure of various parts of the brain, it is essential to remember one guiding principle: *Where the underlying brain will have an adequate postoperative protection by muscle (as in the temporal or suboccipital regions), bone may be removed permanently; but where no muscle protection is available, replaceable bone flaps should be employed.*

The osteoplastic flap, as now employed by most neurosurgeons, provides a hinge of temporal muscle (as well as of scalp) beneath which a permanent decompressive opening may be made if desired.

In Fig. 2 are shown the locations of the incisions most commonly employed for most types of approach to the intracranial contents.

The simple trephine or burr opening employed for ventricular puncture for tapping of an abscess or for subdural exploration is made through a one-inch incision whose edges are held apart with a self-retaining mastoid rectractor. Small nicks are made in the dura and pia, permitting the introduction of the blunt cannula.

The various stages of the osteoplastic craniotomy are shown in Fig. 3. After incision of scalp, fascia, muscle, and periosteum, five or six burr holes are so placed as to outline the flap. Gigli guide and saw are then introduced and the burr holes connected by sawing between them—except across the base of the flap (Fig. 3, B). This segment is cracked by elevation of the flap while firm pressure is made on the line of the base. The dura is then opened in flap-fashion by cutting on progressively larger elevating instruments inserted be-
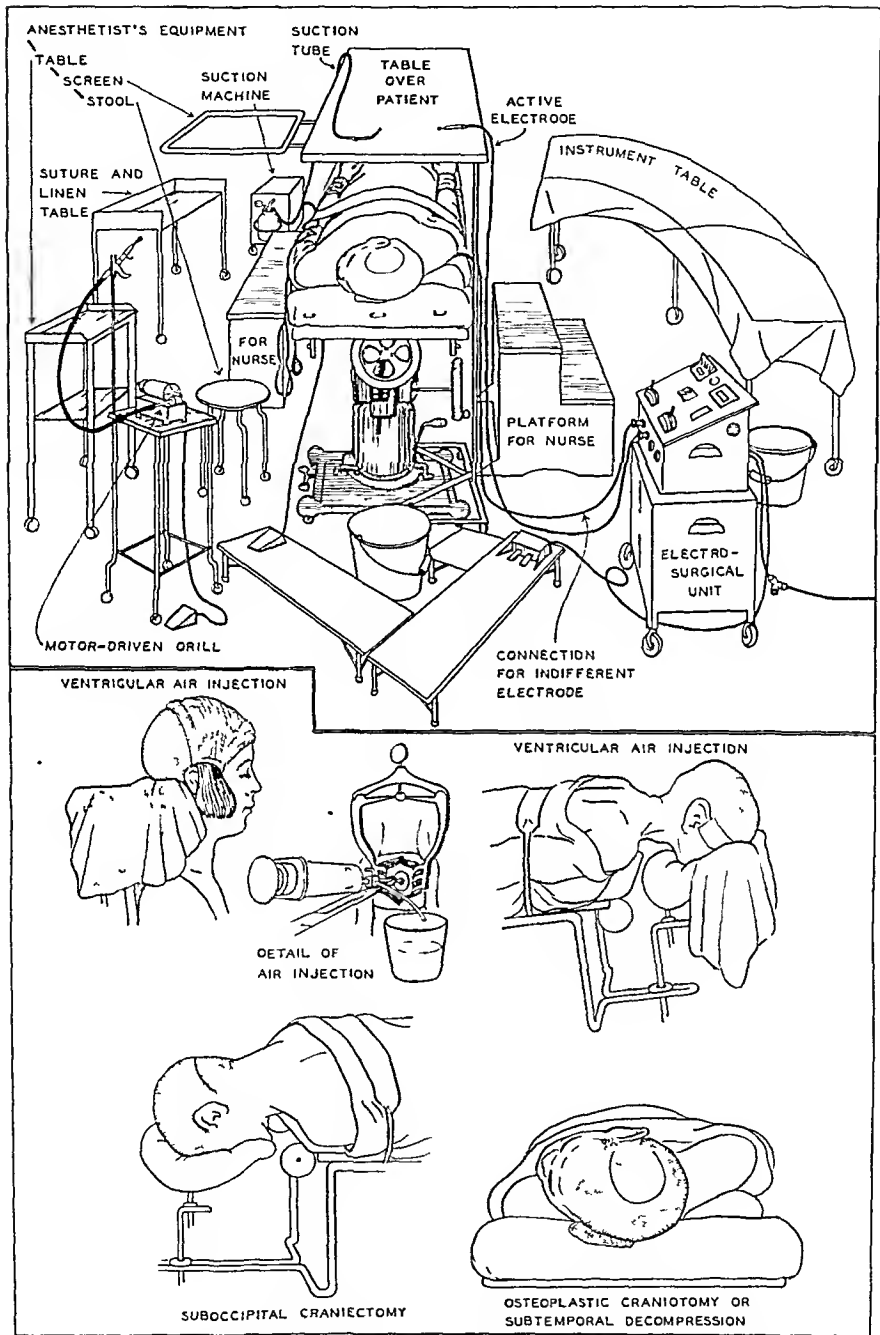
FIG. 1. (*Above*) Diagram of neurosurgical operating room showing author's arrangement of various special devices. (*Below*) Various positions in which patient is usually placed for intracranial operations. As indicated, ventricular air injection may be made either anteriorly or posteriorly.

neath it (Fig. 3, D). The hinge of the dural flap should usually be along the medial border of the exposed area.

area underlying the bony defect (Fig. 3, E).

When the bone flap is replaced, it is sometimes necessary to hold it firmly in
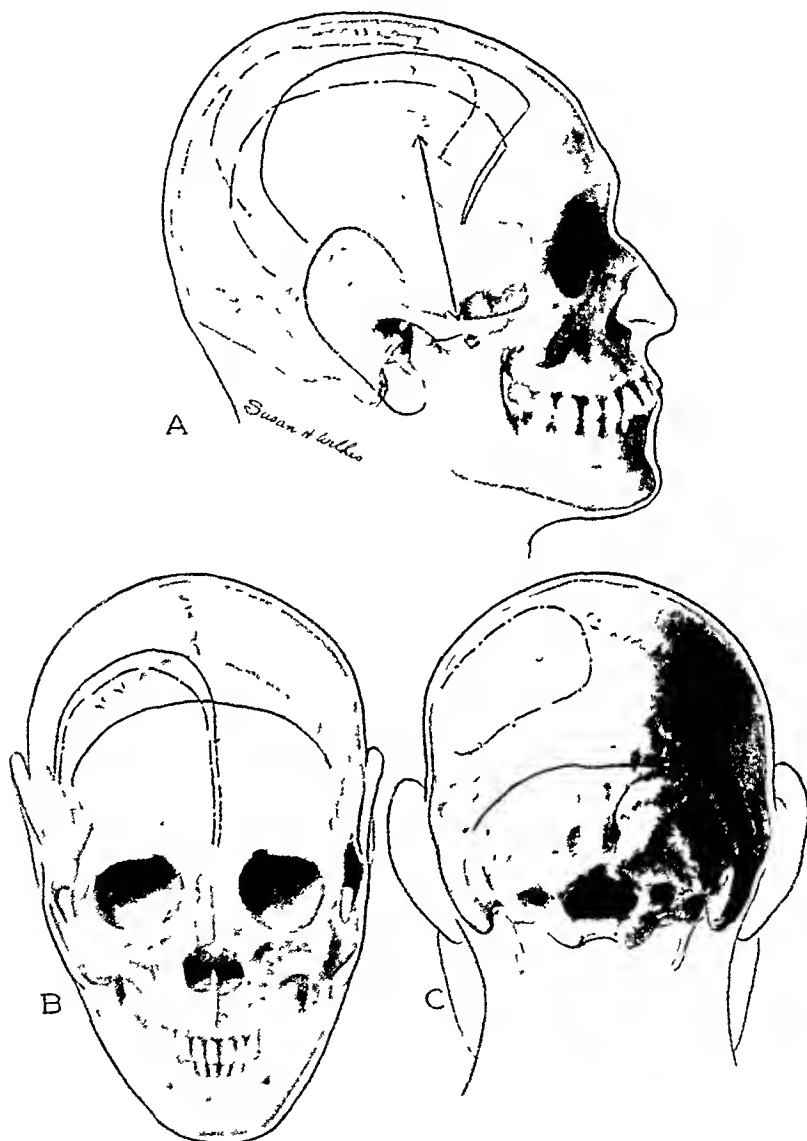


FIG 2. Locations of various incisions for craniotomy.

After conclusion of the intradural procedure, the dura should always be closed tightly, unless it is desired to make a subtemporal decompression. In the latter case, the dura should be left open only in the

place with two or three heavy silk sutures placed through small drill holes (Fig. 3, F).

Subtemporal craniectomy is performed for purely decompressive purposes, or for exposure of the temporal lobe or floor of
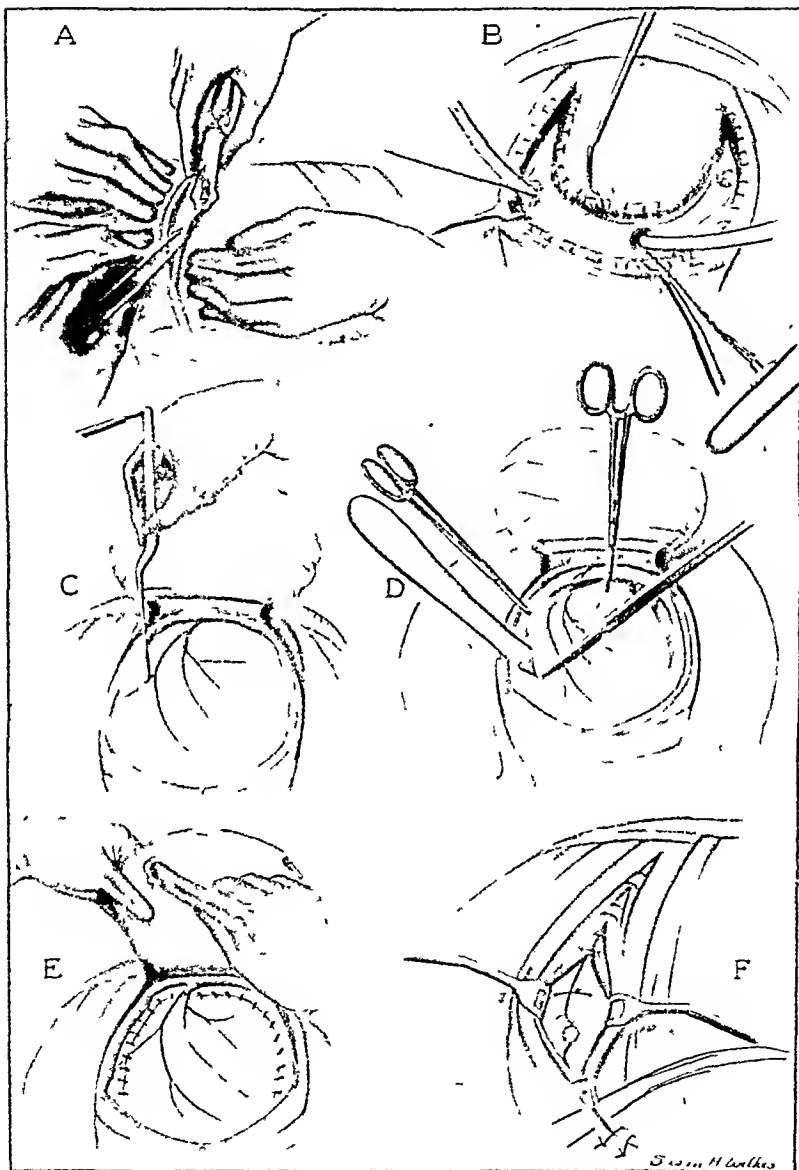
FIG. 3. Steps in osteoplastic craniotomy: (A) Bleeding is controlled by finger pressure while skin clips are applied. (B) Skull is sawed between burr holes by a Gigli wire saw. (C) Dural arteries are coagulated. (D) Brain is protected with a flexible spoon while dura is incised. (E) After intradural procedure, dura is usually completely closed. Wax is applied to bleeding points in bone. (F) Closure is in layers by careful approximation with fine silk sutures.

the middle fossa. In this procedure the muscle is widely retracted and the bone removed piecemeal with rongeurs. If the operation is done for the purpose of decompression, stellate incisions are made in the dura and are left open (Fig 4) Careful closure of the temporal fascia is essential Penfield and Cone have employed an in-

lease the tonsils of the cerebellum and to allow exposure of the lower medulla. In the unilateral procedure, part of the posterior border of the foramen magnum may be removed or not, as desired. The dura is usually closed in the unilateral and left open in the bilateral operation.

Adson and Spurling advocate a straight,
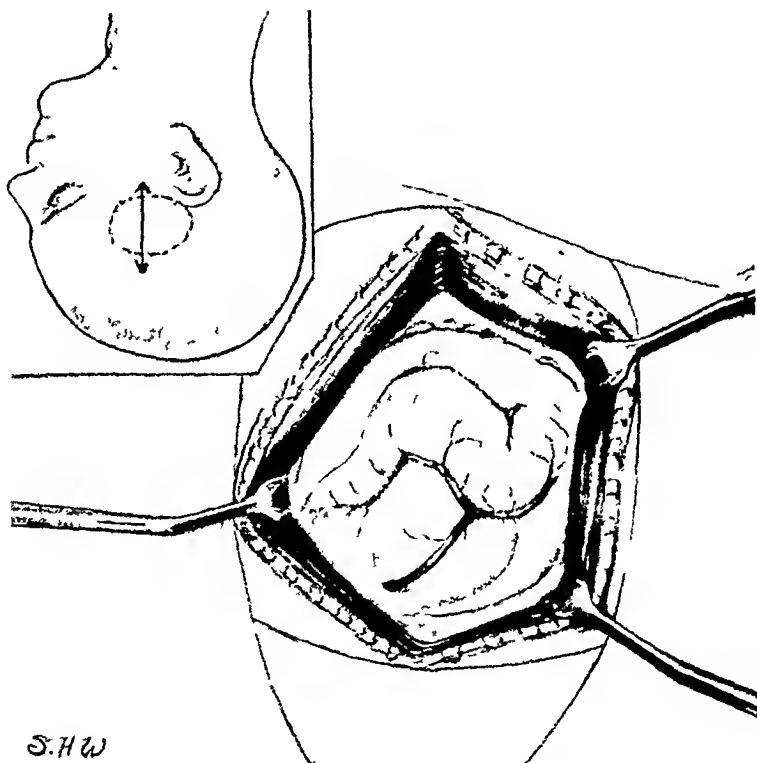


FIG. 4. Subtemporal decompression.

genious method of reflecting the entire temporal muscle downward and subsequently resuturing it to the bone above the decompressive opening

Suboccipital craniectomy may be bilateral or unilateral. The technic of these procedures is shown in Fig. 5. The muscles are reflected downward and the bone removed with rongeurs. In the bilateral operation, usually performed for tumor, the arch of the atlas is resected in order to re-

vertical, paramastoid incision for the unilateral operation.

Suboccipital craniectomy may be combined with a supratentorial osteoplastic flap in the occipital region for attack upon anterior cerebeller lesions or exceptionally large acoustic tumors. In this formidable procedure, it is necessary to divide the tentorium cerebelli from the incisura outward and often to ligate and divide the transverse sinus.
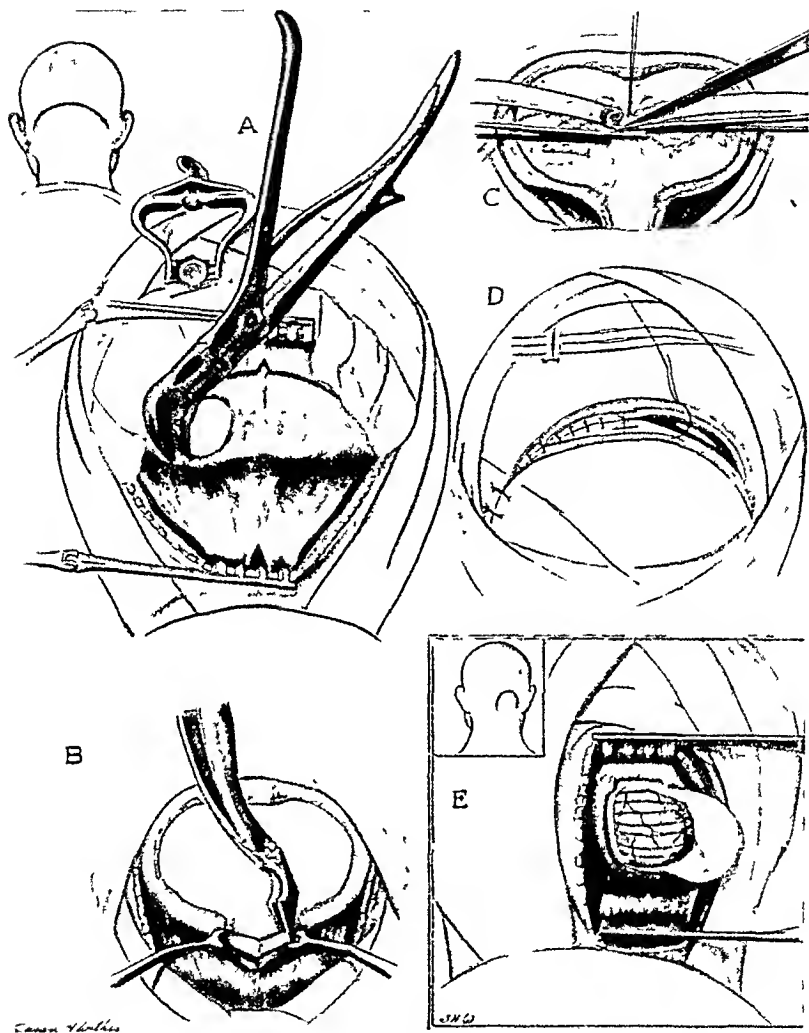
FIG. 5. Steps in suboccipital craniectomy: (A) Muscles are reflected downward; bone is removed with rongeurs. Tapping lateral ventricle diminishes bleeding. (B) Arch of atlas is usually resected. (C) Dura is opened on each side and then divided across midline between a suture above and mosquito clamps below. It is then incised downward in midline. It is not usually closed, since there is a strong muscular protection for cerebellum. (D) Closure is in multiple layers with careful anatomic approximation. (E) Unilateral suboccipital craniectomy.

The technic of laminectomy is discussed in Chapter 17, Surgery of the Spinal Cord.

Hemostasis. The problem of hemostasis presents many special difficulties in neurosurgery, for the bleeding vessels of bone and brain cannot be seized with hemostatic forceps and ligated as can vessels elsewhere in the body.

Many special methods of securing hemostasis have been devised and most of them retain their usefulness, each in its appropriate circumstances. The most frequently used of these methods are shown in Fig. 6.

During the making of incisions, bleeding from the scalp is prevented by firm pressure along the edges of the wound by the fingers of the assistants. In very short incisions, as for ventricular puncture, bleeding may be controlled (and exposure obtained) by stretching the skin edges apart with a self-retaining mastoid retractor. In longer incisions, the scalp is gripped in closely placed Michel skin clips (Fig. 6, A). Alternative methods are the use of straight-pointed hemostatic forceps or of the double skin clips of Adson and Fincher. The former has the disadvantage of filling the region adjacent to the operative field with unwieldy masses of heavy clamps. At the end of the operation, clips or clamps are removed and bleeding permanently controlled by the careful closure with closely placed sutures in the galea aponeurotica and skin.

Bleeding from the bone is best controlled by the application of Horsley's bone wax (Fig. 6, B).

In the dura mater and brain substance, the introduction of electrical coagulation by Cushing altered the whole field of neurosurgery. By means of a damped-wave high-frequency current passed through a fine electrode or through a small pointed forceps, even large veins and relatively large arteries can be rapidly and satisfactorily coagulated. This method has been subjected to considerable criticism by some surgeons, due largely to its misuse. If large masses of tissue are picked up, extensive charring will result, but if the use of the coagulating current is restricted to bleeding from plainly visible vessels or sharply localized bleeding points, and is carried out in a field kept dry by adjacent suction, highly satisfactory results will be obtained and much valuable blood and time will be saved (Figs. 3, C, 6, C, and 6, E). For these reasons, coagulation has its greatest usefulness on the vessels of the dura and pia mater.

The use of silver clips (Fig. 6, F) is of great value on relatively large arteries, the veins entering the dural sinuses and at times on deeply placed cerebral vessels. Implantation of small muscle transplants on dural venous bleeders, particularly in the region of the great sinuses, is an invaluable aid (Fig. 6, D). The diffuse oozing which sometimes occurs in a tumor bed will usually respond to gentle packing with moist cotton pledgets.

Pledgets of fibrin foam, soaked in a solution of thrombin, and applied to points or areas of venous bleeding (as first described by Ingraham and Bailey) are a new and extremely valuable hemostatic adjunct. The fibrin foam may be left in place and will ultimately be absorbed with no more reaction than a similar small fragment of the patient's clotted blood.

On some occasions, fine silk sutures may be used, particularly in opening the dura of the posterior fossa across the mid-line (Fig. 5, C).

Handling Brain Tissue. It is obvious that, just as masses of brain cannot be crushed in clamps, neither can blood be wiped away with rough gauze sponges, nor cerebral tissue be picked up by the fingers or an instrument, as in the case of the intestine, for example. Brain tissue requires the most meticulous gentleness and here, again, special devices and methods are essential.
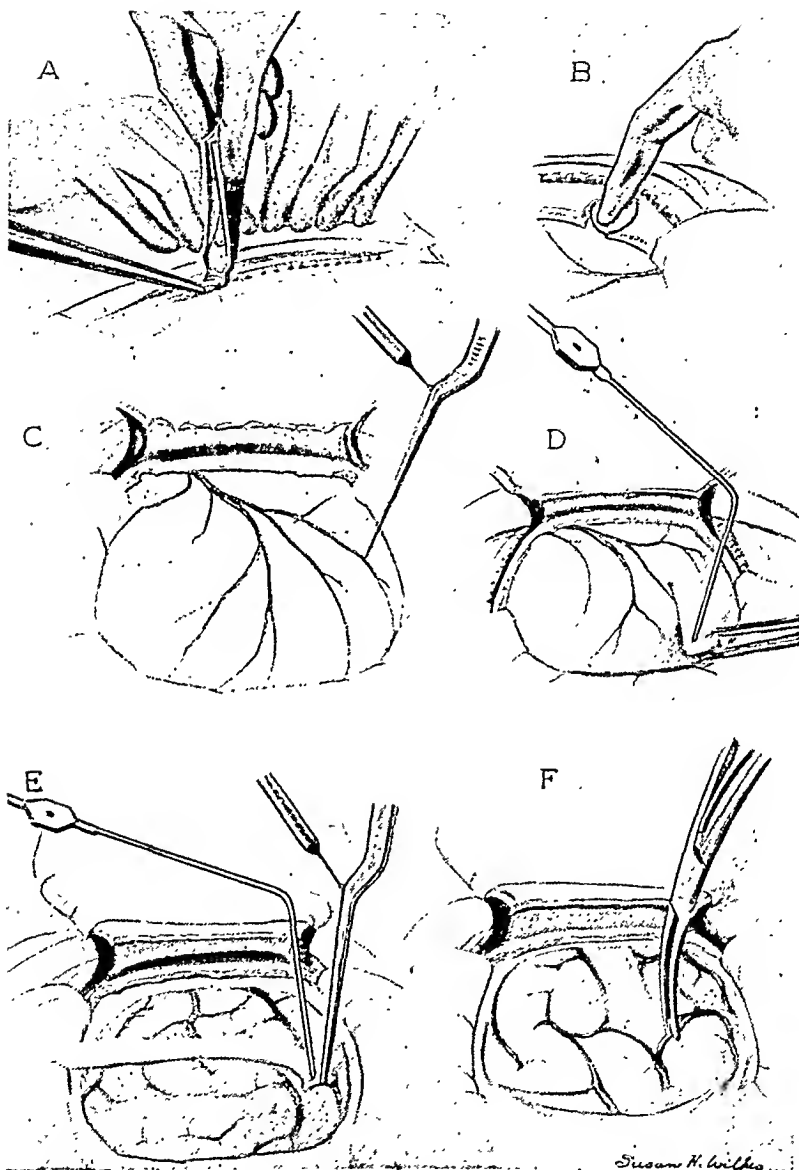
FIG. 6. Methods of hemostasis in neurosurgery: (A) Finger pressure and application of skin clips to scalp. (B) Wax controls bleeding from diploe of skull. (C) Dural vessels are coagulated. (D) Small muscle grafts control venous oozing from neighborhood of dural sinuses. (E) Cortical vessels are coagulated while field is kept dry by suction on moist cotton. (F) Silver clips are useful for cerebral vessels.

trauma to nerve tissue, prolonged anesthesia, and sudden relief of cerebral compression, singly or in combination, sometimes produce a state of shock. If blood loss has been extensive and the blood pressure has fallen rapidly, blood volume must be restored by immediate transfusion. On the other hand, if blood loss has been minimal, the condition may be the so-called "primary shock" due to nerve insult and it will often be wise to wait a short time for spontaneous recovery. Low blood pressure of this type is tolerated surprisingly well for brief intervals. However, its persistence is indication for transfusion of blood or plasma. Transfusions should be given slowly in most instances, in order not to produce renewed hemorrhage as a result of rapidly rising blood pressure. In many cases, the actual life of the patient rests upon the judgment and experience of the surgeon in determining the advisability of and time for transfusion.

Continuous intravenous, subcutaneous, or rectal administration of fluids throughout the operation may be of value in some cases, in prevention of shock.

Postoperative Care. Even more than in the preoperative period, careful observation is of primary importance in the postoperative case. Blood pressure and pulse rate should be recorded frequently. Restlessness may be a sign of hemorrhage. Convulsions, especially if focal in type, indicate cerebral irritation. Increasing paralysis or deepening stupor are danger signs.

An adequate fluid intake must be maintained. Feeding should usually begin within forty-eight hours, by nasal tube if necessary. Bladder and bowel function may require catheterization and enemas. The skin, mouth, and eyes must be protected and cleaned. Frequent changes in position, rebreathing, suction of respiratory secretions, and postural drainage help to prevent pulmonary complications.

Drains should be removed on the first postoperative day and skin sutures may be removed at the same time. If this is done, no further dressing is required, as a rule, until the wound is healed.

These considerations have been discussed in greater detail elsewhere.

## SURGICAL DIAGNOSTIC PROCEDURES

In neurosurgery, as in other fields, the most important diagnostic factors are the careful history and physical examination. Valuable adjuncts, such as perimetry, audiometry, roentgenography, electroencephalography, and cerebrospinal-fluid studies, may be essential. Certain other diagnostic aids, however, are available only through the employment of actual surgical measures. Prominent among these are the following:

Pneumo-encephalography. This procedure involves the roentgenographic study of the intracranial contents after replacement of the cerebrospinal fluid in the subarachnoid and ventricular spaces with a gaseous contrast medium. Both encephalography and ventriculography were first described by Dandy in 1919. Either air or oxygen is commonly employed for injection.

The gas injection is carried out after an ordinary lumbar puncture with the patient in the sitting position. Many complicated devices have been employed, but a simple 10-cc. syringe connected with the lumbar-puncture needle by a three-way stopcock is perfectly adequate if the intracranial pressure is not greatly elevated.* If oxygen is to be employed, it may be bubbled through sterile water and admitted to the syringe through the sidearm of the stopcock.

* It is the author's conviction that spinal air injection is a distinctly dangerous procedure in the presence of increased intracranial pressure, due to the possibility of foraminal herniation. Most of the devices mentioned seek to obviate this danger by the maintenance of a constant intraspinal pressure. In such cases, the author prefers ventriculography.

Cerebrospinal fluid is withdrawn in 5-cc. quantities, each of which is replaced by 4 to 4.5 cc. of gas. Satisfactory roentgenograms of the ventricles may be obtained with as little as 20 cc. of gas, but for best results at least 90 to 100 cc. of cerebrospinal fluid should be replaced with gas.

Gas in the subarachnoid space produces an extremely severe headache. For this reason, general anesthesia is necessary in children and in many adults. The duration of the headache is greatly shortened by the subsequent continuous administration of pure oxygen, which accelerates the absorption of the intracranial gas.

Immediately after the injection of the gas, stereoscopic roentgenograms are made in both the erect and the horizontal position with various aspects of the head adjacent to the film. Best results are obtained with a reversible machine in which the tube may be below and the Bucky diaphragm above the head.

Pneumo-ventriculography. In contrast to encephalography, ventriculography involves the direct injection of air into the ventricles through a surgical opening in the skull. In addition to greater safety in the presence of increased intracranial pressure, it has two advantages: (1) The ventricular system is certain to be visualized (which is not always true after spinal gas injection), and (2) the severe headache resulting from the presence of gas in the subarachnoid space is not experienced when the gas is in the ventricles alone.

Any of the several approaches to the ventricles may be employed. In children, and in uncooperative or irrational adults, it is best to have the patient in the prone position with the head retracted and to make the incisions in the frontal regions. Reversal of the usual cerebellar head rest gives a satisfactory position (Fig. 1, below). In cooperative adults, the patient is in the sitting position and the openings are made in the occipital region (Fig. 1, below). The im-portant consideration in determining the patient's position is that the needle should enter a relatively dependent portion of the ventricle, since the injected air will rise to the top of the ventricle and more complete emptying of the ventricle will be possible.

Local anesthesia should be employed if the patient is able to cooperate at all. One-inch incisions are made approximately 7 cm. above and 3 cm. lateral to the external occipital protuberance, or, if the approach is to be frontal, just above the hairline 3.5 cm. lateral to the midline. The author prefers a unilateral injection, although, occasionally, the air is trapped in one ventricle and it is necessary to make a secondary approach on the opposite side. If the lesion is thought to be in one cerebral hemisphere, the opposite ventricle is entered, since it is likely to be larger than the homolateral ventricle.

After the incision is made, the skin edges are held apart (and bleeding controlled) by a self-retaining mastoid retractor. A single burr hole is made and tiny cruciate incisions are made in the dura. The pia mater is then nicked to permit passage of the blunt ventricular cannula. The latter is fitted with a three-way stopcock and is attached to a 10-cc. syringe as soon as it enters the ventricle. Ventricular fluid is then withdrawn in small amounts and replaced with a slightly smaller volume of air.

Although, in some instances of ventricular dilatation, huge quantities of fluid may be obtained, it is well to remember that, if the ventricles are small, satisfactory ventriculograms can often be made after injection of only a few cubic centimeters of air.

The wound is closed as already outlined earlier in this chapter and roentgenograms are made as in encephalography, except that views are not usually made in the sitting position.

Cerebral Arteriography. Introduced by Egas Moniz in 1927, this procedure has

has been reported by other observers.[5] This figure obviously fails to include the surgically important cases which appear later in infancy or following operation on a meningocele—perhaps numbering as many again.

There are no statistics to show the mortality from hydrocephalus alone, or from associated deformities. The death rate is certainly high. Occasional infants are said to recover with nonoperative treatment and without damage to the brain. The author has never observed this. It is possible that some of the cases rumored to exist (none have been reported in detail) were instances of a temporary osmotic or inflammatory excess of choroid secretion.

Certain infants suffering from hydrocephalus survive to adult life. Most of them are feeble-minded, but in a few instances normal mental development is attained in spite of gross enlargement of the head.[6,7] It has been supposed that a mild hydrocephalus is favorable to outstanding mental development. A survey of the autopsy records of the distinguished men usually selected as examples (Cuvier, Helmholtz, Gauss, Menzel) lends no support to such an idea.

## DIAGNOSIS AND PROGNOSIS IN INDIVIDUAL CASES

Nothing is to be gained by any radical treatment of cases of hydrocephalus in which the head is enormous at birth, or where other obviously fatal external defects exist.

The symptoms which usually first give rise to a suspicion of the existence of hydrocephalus are a slight enlargement of the head or persistence of fullness of the fontanel when the head is elevated. This may come on spontaneously at any time within six months after birth, or after operation for meningocele. The child becomes dull or fussy, feeds poorly, and may vomit. Two questions then present themselves. The first is, what is the origin of the increased intracranial pressure? The second is, what is the outlook for the child's mentality if the pressure is relieved?

The question as to the type of hydrocephalus present is ordinarily easily answered if the condition arose following an operation for meningocele. If it came on spontaneously, it is sometimes settled by an x-ray of the skull, which shows not only separation of sutures but also a fenestration of the bone in many cases of congenital hydrocephalus (Fig. 7).

Further information may be obtained by puncture through the anterior fontanel. This should be performed with the patient in a recumbent position. If the baby is placid, accurate pressure measurements may often be obtained without the use of an anesthetic; if there is any difficulty, however, the administration of a hypnotic such as pentobarbital is advisable. The normal infant should have an intracranial pressure of 50 to 80 mm. of water. If the pressure is normal or nearly so, operation may be safely postponed.

Aside from measurement of pressure, it is of great importance to measure exactly the depth at which fluid is obtained. The scalp and skull are less than 0.5 cm. in thickness. If fluid is obtained at this depth, it is probably subdural in origin. Arachnoid fluid is practically never obtained. The depth beyond the dura is a measure of thickness of ventricular wall, naturally of prognostic importance.

The fluid should be examined for cells, and a determination of protein, sugar, and gold-sol reaction should always be made. Meningitis in infants—apparently especially in premature infants—may exist with relatively little effect on the general condition or temperature, and is easily mistaken for congenital hydrocephalus. The presence of blood or a xanthochromic fluid or a protein content of 100 mg. or more usually means a subdural hygroma.

Usually no other special examinations

are needed for diagnosis. Ventriculography in hydrocephalic infants carries such a high mortality—almost half that of endoscopy—that it should be avoided if possible. Injection of dye into the ventricles is seldom of decisive value. If the results of (under a soporific) and the degree of dynamic block demonstrated. In case of doubt, air may be injected into the ventricles.

Quite as important as the neurologic diagnosis is an estimate of the infant's men-



FIG. 7. X-ray showing fenestration of the skull.

other examinations are inconclusive or apparently contradictory, one or the other of these procedures may be carried out, but they are seldom essential.

In cases of atresia of the aqueduct, hydrocephalus is usually either present at birth, or develops suddenly with high pressure. Obstruction of the fourth ventricle by tumor also produces an acute hydrocephalus, but late in infancy. If either is suspected, simultaneous ventricular and lumbar puncture should be performed

tal activity. Hydrocephalic babies who feed poorly, take no interest in their surroundings, and do not cry or respond, are presumably the victims of extensive cerebral defects or irreversible damage to the brain, and should seldom be operated upon. They practically always die whether the pressure is relieved or not. If there is any question whether the symptoms are due to pressure alone, daily ventricular punctures may be done, to see if improvement occurs

More difficult is to judge how near nor-

mal a somewhat responsive child is. The mother's estimate is rarely to be trusted. An experienced psychometrist or child psychologist is often of great help in deciding. If none is available, a careful inventory should be made of all the child's activities —reaching for objects, fixing and coordinating the eyes, evidence of recognition of mother or nurse, spitting unpleasant objects (paper soaked in vinegar) out of the mouth, repeating syllables.

There are several brief texts which describe tests suitable for determining the degree of development of young infants. The *Iowa test scale for young infants*[8] is inexpensive and easily obtainable. A more extensive treatise is Testing Children's Development from Birth to School Age by Buehler and Hetzer.[8] The following summary is taken from the latter book:

*Normal Activities of First Month of Life:*
1. Turning head when cheek is touched.
2. Clutching at an object which touches hand.
3. Reacting positively to being picked up.
4. Reacting positively to a mild noise.
5. Looking at a subdued light.
6. Reacting to a shadow.
7. Reacting negatively to unpleasant tactual stimulation.
8. Reacting unspecifically to a cardboard cover placed over crib.
9. Lifting head briefly while in prone position.
10. Opening mouth after withdrawal of source of food.

*Normal Activities of Second Month of Life:*
1. Turning head toward a noise.
2. Listening to a bell.
3. Reacting specifically to four acoustic stimuli.
4. Staring at a light.
5. Following a moving object with eyes.
6. Following moving object outside field of vision with eyes.
7. Reacting unspecifically to a cloth thrown over it.
8. Keeping head erect when lifted up.
9. Reacting positively to human voice.
10. Reacting specifically to feeding position.

*Normal Activities of Third Month of Life:*
1. Searching head movements during a prolonged sound.
2. Fixating a distant object.
3. Looking around while being carried.
4. Following a moving object with eyes.
5. Listening to a rattle while in prone position.
6. Holding head up while in prone position.
7. Experimenting movements.
8. Returning glance of adult with smiling or cooing.
9. Cooing.
10. Looking for a disappeared object.

*Normal Activities of Fourth Month of Life:*
1. Looking for source of a sound.
2. Reacting to an optical rather than to a simultaneous acoustical stimulus.
3. Feeling of objects.
4. Examining an object visually.
5. Following a moving object with eyes when in prone position.
6. Holding head and shoulders erect while in prone position.
7. Moving arms and legs over undersurface while in prone position.
8. Reacting negatively when experimenter stops playing.
9. Reacting to mask.
10. Holding rattle.

*Normal Activities of Fifth Month of Life:*
1. Looking at a colored paper longer than at a white one.
2. Looking at an object while holding it.
3. Grasping a touched object.
4. Stretching arms toward an object in view.
5. Attempting to remove cloth while in dorsal position.
6. Lying supported only by palms of hands.
7. Raising head and shoulders with support.
8. Following movements of adult in room.
9. Reacting to novelty of a situation.
10. Manipulating an object.

*Normal Activities of Sixth Month of Life:*
1. Distinguishing between an object and its environment.

2. Distinguishing between bottle and a rubber doll.
3. Grasping object in view with one hand.
4. Removing cloth while in dorsal position.
5. Raising head and shoulders while in dorsal position.
6. Raising head and shoulders with assistance.
7. Reflecting friendly and angry facial expressions.
8. Reacting negatively to withdrawal of a toy.
9. Expectation.
10. Defense reaction to withdrawal of a toy.

*Normal Activities of Seventh Month of Life:*

1. Grasping table edge.
2. Reaching in direction of a light.
3. Turning around while sitting with support.
4. Removing cloth while in prone position.
5. Sitting with support.
6. Turning from back to side.
7. Actively seeking contact.
8. Looking for a lost toy.
9. Imitative beating on table.
10. Manipulating a stationary object with a moving one.

*Normal Activities of Eighth Month of Life:*

1. Reaching for an object outside crib.
2. Removing cloth while sitting with support.
3. Pushing away a disagreeable stimulus.
4. Remaining in sitting position.
5. Locomotion.
6. Taking a toy away from adult.
7. Playing peek-a-boo.
8. Taking an object from adult's pocket.
9. Manipulating two toys.
10. Changing position to reach an object.

*Normal Activities of Ninth and Tenth Months of Life:*

1. Grasping two objects when sitting without support.
2. Removing cloth when sitting without support.
3. Sitting without support.
4. Crawling.
5. Responding specifically to gestures.
6. Attracting adult's attention.

7. Uncovering a hidden toy.
8. Imitative drumming with one stick.
9. Beating two spoons together.
10. Grasping same object twice.

Exact directions for performing the necessary tests, with outline of the materials needed, are given in the publications cited.[8] Most of the materials can be improvised with little trouble. Obviously, not all of the tests for a given age are passed by normal children. On an average, an infant of six weeks will pass all except one or two of the tests for the first month, and about half the tests for the second month. As a rule of thumb, a hydrocephalic infant scoring 50 per cent of the expected performance is a reasonable operative risk.

## TREATMENT

Several nonoperative forms of treatment have been suggested—administration of diuretics,[9] irradiation of the choroid plexus,[10] and postural drainage, keeping the infant propped in a sitting position.[11] Series of case reports, giving pressures or head measurements before and after such forms of treatment, have not been published. In favorable cases, in which the infant's mental activity approaches the normal and there are no definite contraindications for operation, conservative methods of treatment should not be used for more than two or three weeks if the intracranial pressure is above 150. If it is above 300, a moderate emergency exists, and operation should be undertaken at once.

Choice of Form of Operation. The safest and most effective form of treatment of hydrocephalus is endoscopic coagulation of the choroid plexus. According to Davis,[12] this operation was first successfully carried out by Lespinasse in 1910, by means of an operating cystoscope. It has been sporadically utilized since. The whole subject was put on a sound physiologic basis for the first time by Dandy in 1918. He proposed destruction of the choroid

plexus by an open operation,[13,14] which is considered below. In 1934, a special glass ventriculoscope with provision for bipolar coagulation was introduced,[15] and this greatly increased the safety of the operation. Almost simultaneously and independently, Scarff[16] began using a special metal ventriculoscope, employing unipolar coagulation.

Dandy's method of operation, first announced in 1922, consists of inserting a speculum (Kelly cystoscope) through the cortex, emptying the ventricle, and removing the choroid plexus after clipping its ends. Both sides are done at one sitting. Writing in 1932, Dandy states: "Although the author suggested removal of the choroid plexus from both lateral ventricles for this type of hydrocephalus, the survival period has not been long enough to be certain of cures."[17]

In a later article in 1938, Dandy[18] states: "I have had several undoubted cures resulting from this method," and reports two cases. He suggests that removal of the choroid plexus in the fourth ventricle be carried out if removal of the glomus is insufficient. As a last resort, he suggests resecting the plexus in the body of each lateral ventricle—a procedure which is usually carried out as a part of endoscopic coagulation. He presents no operative statistics.

Technic of Endoscopic Coagulation of Plexus. The bipolar ventriculoscope* (Fig. 8) is recommended for the following reasons: There is practically no space wasted in the cross section; all of it except the electrodes is devoted to the transmission of the image. This large optical aperture permits far clearer vision in a cloudy medium than do instruments of the cystoscope type. The diameter of the instrument is smaller than that of any other operating endoscope. It has a deep focus; structures

* Manufactured by the Electro-Medical Laboratories, Inc., Holliston, Mass.

in the ventricle may be seen at a distance of several centimeters, or in direct apposition. Nothing projects outside of the field of vision. Most important of all, the current passes only between two closely placed electrodes, actually in the field of vision, and is therefore confined to structures floating in the fluid. When unipolar coagu-
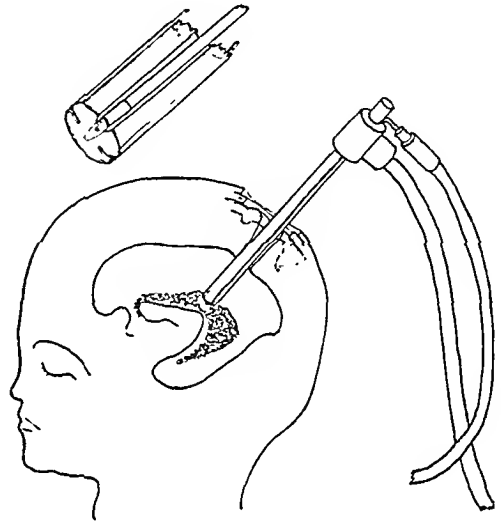


Fig. 8. Glass ventriculoscope in place.

lation is employed, the current necessarily passes through the basal nuclei, often producing softenings.[15]

The glass ventriculoscope has certain disadvantages. There is some difficulty in obtaining proper glass, and in grinding it to exactly the correct form. Some of the earlier instruments especially were unsatisfactory in one or the other respect. It is fragile. The front surface is easily scratched or pitted by permitting sparks to pass between the electrodes through the air. The electrodes are easily torn out. The instruments cannot be boiled or autoclaved, but must be sterilized by immersion in 70 per cent alcohol.

Technic of Operation. Inhalation anesthetics are to be avoided. Tribromethanol

by rectum, sodium pentobarbital by mouth, or one of the soluble barbiturates subcutaneously is satisfactory. Anesthesia may be supplemented by minute doses of morphine.

When the infant is immobilized, the entire head is shaved. (This is a favorable opportunity to take a photograph.) The patient is placed face down on an elbow-high table, with a folded blanket under the right hip and shoulder, and the head turned as far to the left as it will go. The head is elevated on sandbags, and kept in this rotated position so that the site of proposed incision is approximately uppermost (Fig.
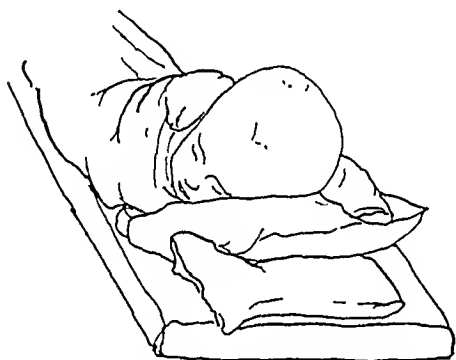


FIG. 9. Position of patient's head on sandbags.

9). A scrub with alcohol followed by bichloride is an efficient preparation.

The incision should be a curved one, about 5 cm. long, to give access to a spot 3 cm. from the midline in the parieto-occipital region, well away from the motor cortex. The skin is infiltrated with procaine, and the area of incision outlined with a scalpel. Draperies are applied—a mastoid sheet is excellent for the purpose. The incision is then carried cleanly through the skin and periosteum in one sweep. Few hemostats are required to check bleeding. A self-retaining retractor is inserted.

The bone is perforated with a hand drill or a small periosteal elevator. It is removed to expose an oval area of cortex

about 2 by 3 cm. Before the dura is opened, the pressure in the ventricle should be measured by means of a manometer attached to a needle, if this has not already been done. The dura is then opened by a straight incision, and any large vessels in the underlying pia are clipped or stitched to it. An incision about 2 cm. long is then made through the pia, and extended into the ventricle with the handle of a scalpel.

At this point, the operator puts on a sterile celluloid mask, extending over the mouth and nose, which otherwise would occasionally touch the top of the instrument. The operating room is completely darkened. The instrument, with wires attached to the lamp battery and to the diathermy apparatus, is carefully inspected to make sure both ends are clean. The lamp carrier is retracted within the instrument, which is then plunged into the ventricle. As soon as the tip is in fluid, the lamp carrier is cautiously pushed forward until adequate illumination is secured.

The difficult part of the operation consists in locating and destroying the plexus without injuring the walls of the ventricle. This is accomplished by moving very slowly down the septum pellucidum, and following a vein from its smaller tributaries to its termination adjacent to the plexus. When the fluffy pink plexus is encountered, the tip of the instrument is placed directly upon it. A coagulating current, barely strong enough to cause a change of color of the tissues, and never permitted to spark, is passed for about a second for each area touched. The plexus is followed, first on its medial, then on its lateral surface, well into the anterior horn, over the glomus, and as far as possible into the temporal horn. Particular care should be taken to move the glomus about and turn it over, for it often lies in folds.

During the course of coagulation, the front surface of the instrument tends to become covered with precipitate, and it

must often be removed for cleaning. Relatively little bleeding may seriously obscure visibility, which however usually improves as time goes on. Some of the blood may be washed out by syringing with large volumes of Ringer's solution. Care should be taken not to get air into the ventricle or under the dura. It should also be remembered that any bubbles given off during coagulation are a mixture of hydrogen and oxygen, and therefore explosive.

Sometimes there is a perforation of the septum, and it is possible to reach the contralateral choroid plexus. Usually, however, it is best to content oneself with a thorough destruction of one side at a sitting.

When the plexus is thoroughly coagulated—which ordinarily takes 30 to 90 minutes—the instrument is withdrawn. The dura is carefully sutured. It is desirable to sew the periosteum over the dural incision. Five thousand units of penicillin should be injected into the ventricle. The skin is closed separately. A small collodion or latex cocoon is the only dressing required.

A transfusion or infusion is desirable, and the child can then be returned to its usual schedule as soon as it recovers from the anesthetic.

No particular after-care is needed. Feeding may be difficult for a few days. If the fontanel remains tense, it may be punctured to remove fluid, which is then usually found blood-stained. As soon as the fluid becomes clear, or within two weeks, the advisability of operating on the opposite side may be considered. If there is any real doubt about it, re-operation is best postponed until it becomes clearly necessary.

Occasionally re-operation also fails to give adequate relief. If this occurs, the first operative wound or both should be reopened and the plexuses inspected to see if any tags of secreting tissue are left behind.

Results of Operation; Mortality. Forty-six operations of this type have been performed in 28 cases of hydrocephalus by the author, and Scarff[16] has reported five other cases. In all, including those who died, intracranial pressure was substantially decreased by the operation. In the last 25 operations on 20 patients, there have been three "operative" details. Ten of the patients have died after discharge from the hospital. Two of these died obviously from a recurrence of increased intracranial pressure after a unilateral operation, when external circumstances made reoperation impossible. The remainder died of intercurrent disease as a result of pre-existing defects of the brain or of the cord, or of unknown causes.

The ultimate fate of children so operated upon is often questioned, doubtless because of the prevalent confusion between enlargement of the ventricles from atrophy and dilation from increased pressure. Curiously enough, no similar problem is ever brought up in relation to infants suffering from the simpler meningoceles, an allied malformation. Five of the hydrocephalic patients from the early days of the operation have now been followed for periods of from three to six years (Fig. 10). All appear to be within a normal range of intelligence for their respective ages, two even distinctly above average.

Other Types of Operation for Hydrocephalus. Puncture of the corpus callosum (von Bramann) in the treatment of hydrocephalus has been abandoned, as the openings invariably close. So do openings over the convexity of the brain.

In cases in which hydrocephalus coexists with spina bifida, the presence of an Arnold-Chiari malformation of the medulla may be suspected. Operative treatment of this condition has been reported by D'Errico.[19] Of his six cases, one died but three of those who survived appeared relieved. Similar operations in adults have been re-

FIG. 10. Intraventricular pressure.

ported by Parker and McConwell.[20] A standard suboccipital decompression is performed, the laminae of the first two or three vertebrae are removed, and the adhesions about the sac are carefully dissected free. In cases in which cauterization of the plexuses does not give relief, this more dangerous operation sometimes brings the pressure to a tolerable level.

Drainage operations, such as anastomoses between arachnoid and ureter or peritoneum have been carried out with success in isolated instances. The technic is not yet standardized. Davidoff's article[21] gives a review of the situation, which remains unchanged since.

Atresia of the aqueduct of Sylvius may be treated by catheterization of the aqueduct (Dandy, 1920,[22] Fraser and Dott[23]). After removal of the roof of the fourth ventricle, a small rubber catheter is gently pushed toward its upper end, and past any obstruction. Two cases have been reported. Dandy[17] has since apparently abandoned the operation, and advises against it. No late follow-up reports are available.

Obstruction of either aqueduct or fourth ventricle may also be relieved by puncture through the wall of the third ventricle by a subfrontal or transtemporal approach (Dandy, 1920,[22] 1932,[17] Stookey and Scarff, 1936,[24] and others). The latter report six cases with four successes. The same object may be accomplished by means of a ventriculoscope as described by Mixter, 1925,[25] and by Scarff.[16] Each reported one case There is some reason for fearing that the opening will eventually close in some instances, although Dandy has reported a survival of ten years in one case.[17]

## CONCLUSION

There exists a widespread pessimism in regard to the possibility of cure of hydrocephalus, even in many neurologic clinics. A survey of the literature, and of one of the groups of cases subjected to operation, shows clearly that the subject is by no means hopeless. The important first essentials are the proper selection of cases, and early operation. Third comes the choice of operation, with regard to the safety of the

patient's life and brain. To be sure, it is doubtless true that a majority of all cases of hydrocephalus are beyond successful treatment, but this is no reason for neglecting the minority, which is a large one.

## SUBSEQUENT NOTE

Since the above article was written, the author has had occasion to carry out coagulation of the choroid plexuses in two cases of meningocele which were considered otherwise inoperable. Both were tense and leaked from time to time. In one, a large sessile sac in the lumbar region, the defect flattened down to a dense scar, was covered by firm skin. Unfortunately, the patient died of an intestinal disorder six weeks later.

In the second case, the meningocele was frontal, presenting between the eyes and overshadowing the nose. Relief of intracranial pressure permitted it to shrink to a small firm nubbin of tissue, which promises to subside still further without a local operation.

Scarff[26] has recently published a longer series of cases treated by endoscopic coagulation. Mortality has been low. Of particular interest is the growth in thickness of the cortex, demonstrated by ventriculography before and after operation.

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# 3

# Craniocerebral Trauma

## R. Glen Spurling, M.D.

## INTRODUCTION

During the past two decades, trauma to the head has become one of the major causes of death. The number of severe head injuries has increased in direct ratio with each increase in the speed of transportation. Because of the widespread distribution of these cases it is obvious that only a small percentage of them can be cared for by qualified specialists in neurology and neurosurgery. It is imperative, therefore, that the general practitioner, and especially the general surgeon, be thoroughly familiar with the broad general principles upon which the modern treatment of head trauma is based. To approach the subject with understanding he must have some knowledge of the basic anatomy, physiology, and pathology of the brain. It is highly desirable that the reader consider carefully the following cursory review of the pertinent anatomic, physiologic, and pathologic data before proceeding to the section on treatment. To further stimulate the inquisitive reader, a bibliography of fundamentally important articles has been placed at the end of Chapter 4.

## ANATOMY

The skull, except in the early years of life, is a rigid box incapable of variations in size to accommodate for variations in the volume of its contents. Aside from the tiny openings through which cranial nerves and blood vessels pass, there is but one opening in the adult skull; i.e., the foramen magnum. It is through this foramen that the brain stem joins the spinal cord and, furthermore, it is approximately at the level of this foramen that many of the important medullary structures are located. However, it must be remembered that the skull has sufficient elasticity to permit the transmission of force to the cranial contents without demonstrable fracture. Also, when motion of the head is suddenly arrested as in most automobile injuries, the brain presses forward against the skull with great force. As a matter of fact, many fatal brain injuries are not associated with demonstrable skull fractures.

The brain and spinal cord are covered by three membranes—the dura mater, the arachnoid, and the pia mater (Fig. 11). The first of these membranes, the dura mater, is a tough fibrous tissue envelope lined by endothelial cells. In the skull it may be divided into an outer and an inner layer; the outer layer forms the endosteal lining of the cranial bones, and the inner layer (cerebral dura) envelops the brain.

Two extensions of the dura mater, the falx cerebri and the tentorium cerebelli, partially divide the cranial cavity (Fig. 12). The falx cerebri is a sickle-shaped structure longitudinally placed between the two cerebral hemispheres. The tentorium cerebelli is a horizontally placed par-

tition separating the cerebellum from the cerebral hemispheres. The incisura cerebelli is an opening formed by the free anterior margin, and it is at this level that

sinuses which in turn empty into the internal jugular veins (Fig. 13). Trauma in the region of any sinus may cause rupture of the sinus itself or damage to the thin-
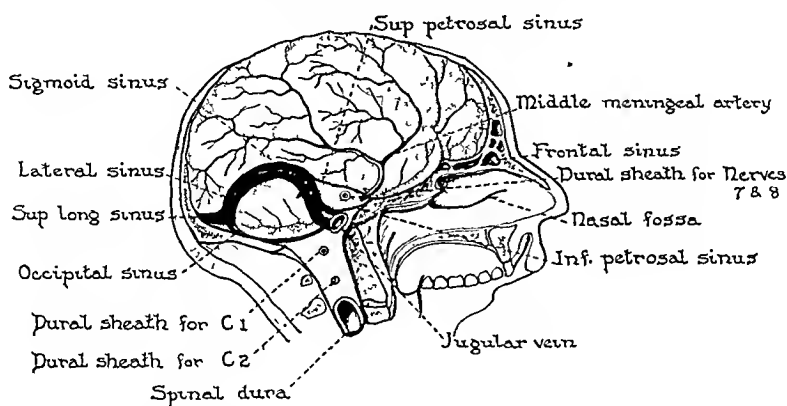


FIG. 11. Dura mater middle meningeal artery and lateral sinus. (After Tilney and Riley: Form and Functions of the Central Nervous System, New York, Paul B. Hoeber, Inc.)
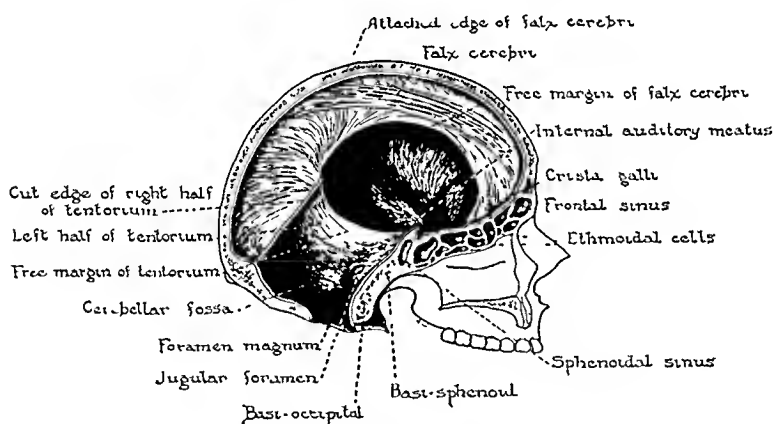


FIG. 12. Interior of skull showing relations of falx cerebri and tentorium cerebelli. (After Tilney and Riley: Form and Functions of the Central Nervous System, New York, Paul B. Hoeber, Inc.)

the important mesencephalic structures are located.

The great venous sinuses lie between folds of dura mater; the superior sagittal sinus, the largest of the group, occupies the superior portion of the falx cerebri. The two lateral (transverse) sinuses are located in the superficial margin of the tentorium cerebelli. The venous blood from the brain flows into the various dural

walled cortical veins which empty into it. Blood escaping from the sinus or from one of the parasinus veins seeps into the subdural space, producing the common lesion known as subdural hematoma.

The middle meningeal artery enters the floor of the skull through the foramen spinosum and runs through a bony groove in the temporal bone to be distributed to the dura mater (Fig. 14). The groove may

become a tunnel as a result of bony bridging across the groove on the intracranial side. Due to its intimate relationship to the temporal bone, the artery is often damaged stripping, additional venous and arterial tears, and even a larger tear than the original one, may develop. Extradural hematoma is one of the most important
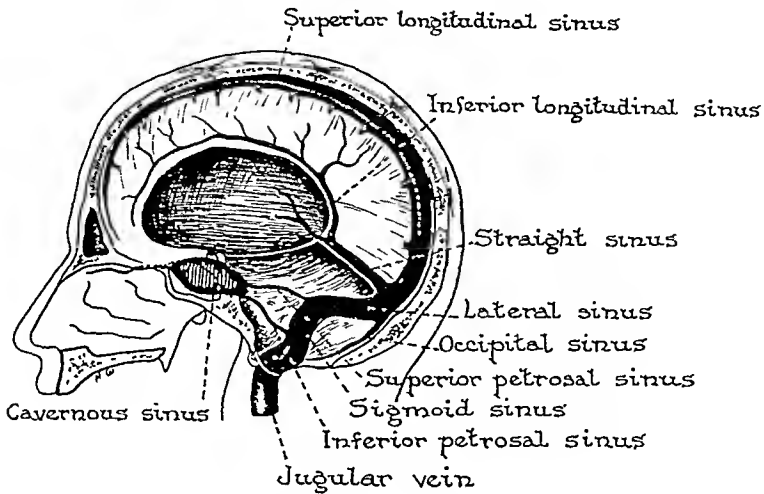


FIG. 13. Diagram of cerebral dural sinuses.
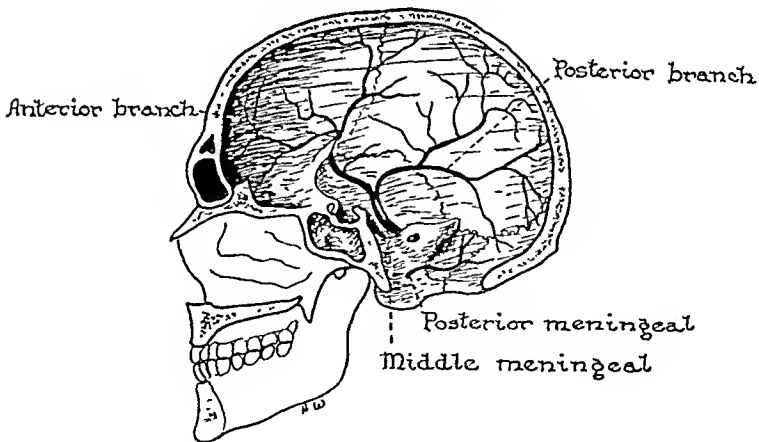


FIG. 14. Diagram of course of middle and posterior meningeal arteries.

by fractures in this region. The blood from a torn meningeal artery accumulates rapidly between the dura mater and the skull, and as the extradural clot enlarges the dura mater is progressively stripped from the cranial bones. In the process of surgical complications of head trauma.

The cerebrospinal fluid is secreted chiefly in the choroid plexus of the lateral ventricles. It passes through the ventricular system to the base of the brain where it flows over the surface of the brain into the

cerebral subarachnoid spaces. Most of the fluid is absorbed into the venous sinuses through the arachnoidal villi and granulations (Fig. 15). The cerebrospinal fluid acts as a space-compensating mechanism between the brain which undergoes volu-

When brain tissue is lost by disease or trauma the space thus created is filled with cerebrospinal fluid.

## PHYSIOLOGY

An attempt to outline all of the known
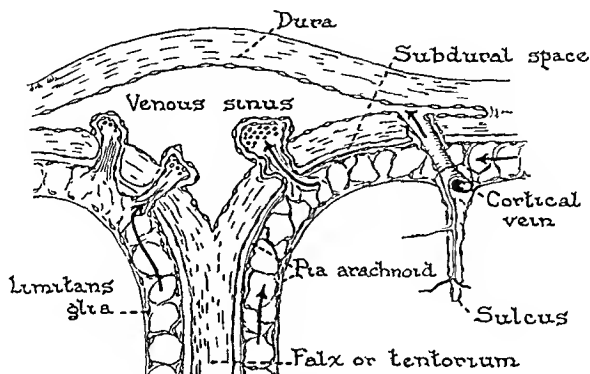


FIG. 15. Diagram to show relations of pia-arachnoid, arachnoid villi, and cortical veins to dural sinuses. (Cushing—Weed.)
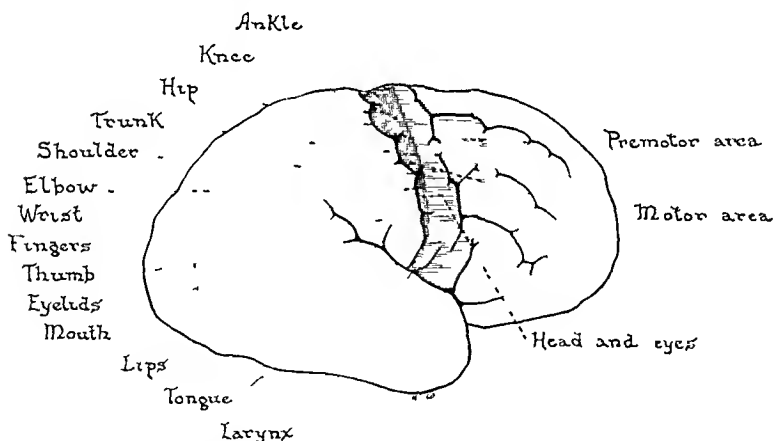


FIG. 16. Diagram of the true motor cortex and the premotor area. (Courtesy, R. Glen Spurling: Practical Neurological Diagnosis, Springfield, Ill., Charles C. Thomas, Publisher.)

metric changes and the skull which is inelastic The normal alterations of cerebrospinal fluid pressure are brought about by changes in the blood volume Sudden changes of intracranial volume are compensated for by variations in the volumes of the blood and the cerebrospinal fluid.

physiology of the cerebral cortex for purposes of explaining the phenomena of neurologic signs is obviously beyond the scope of this chapter However, it should be remembered that certain gross areas of localization are well known. The frontal poles, apparently, are concerned primarily

with psychic activity—cerebration, concentration, and judgment. The motor cortex is the source of all voluntary muscular activity, and when damage occurs to it a contralateral hemiplegia results. If there is irritation to these cells in addition to destruction, jacksonian epileptiform seizures in the contralateral half of the body are observed (Fig. 16).

The speech mechanism is contained in a broad area of cerebral tissue in the dominant hemisphere centering about the junc-

Behind the motor area lies the great sensory receiving area of the brain. Damage to this region produces certain sensory disturbances (discriminative) of the contralateral half of the body.

The occipital poles of the brain, especially the calcarine cortex on the mesial surface, constitute the visual centers. Damage to these areas produces defects in the field of vision depending entirely upon the amount of visual cortex involved (Fig. 18).
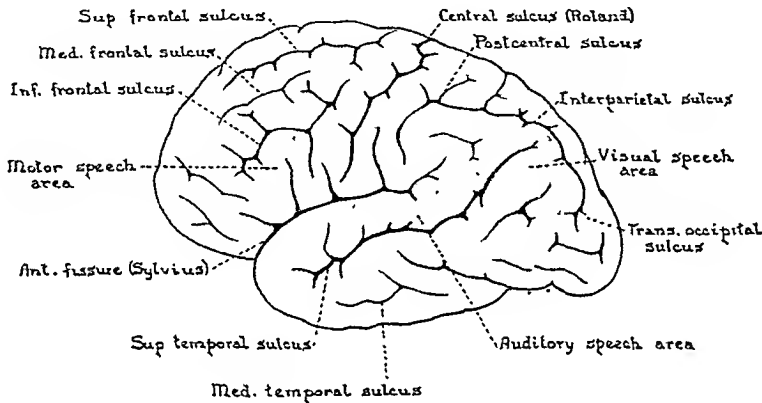


FIG. 17. Lateral view of left cerebral hemisphere (diagrammatic), showing cortical areas concerned with speech. (Courtesy, R. Glen Spurling: Practical Neurological Diagnosis, Springfield, Ill., Charles C. Thomas, Publisher.)

tion of the rolandic and sylvian fissures. It should be understood that the dominant hemisphere refers to the *left* cerebrum in the right-handed and to the *right* cerebrum in the left-handed. In the ambidextrous individual it may be very difficult to be certain which is the dominant hemisphere. If the anterior part of the speech mechanism is involved primarily, the speech defect will be chiefly motor; that is, the patient cannot express himself but can understand spoken and perhaps written words. If the damage is more extensive, both speech and understanding will be affected and the patient may appear to be dumb (Fig. 17).

The basilar structures of the brain, especially the hypothalamus and mesencephalon, are concerned with important reflex activity such as the control of blood pressure, water metabolism, and temperature regulation. Although neoplasms may reach surprising size in these vital areas with only minimal symptoms, acute injuries result in disturbances of vital functions, often with glycosuria, hyperthermia, and death.

## PATHOLOGY

Again space will permit listing only the more common craniocerebral lesions resulting from trauma, and a brief discussion of

the gross pathology of each. For the sake of clarity they must be taken up individually, but it must be remembered that the pathology in each case varies in type and extent with the amount of force applied, the point of impact, and the variable blows and, consequently, have suffered more brain or vascular damage. Often when a depressed fracture results from injury there is less generalized brain damage because force is dissipated locally. In such instances, the prognosis for life may



M. superior oblique

Retina

N. II

Optic chiasma

N IV

Optic tract

Thalamus

Med. geniculate body

Lat. geniculate body

Pulvinar

Sup. colliculus

Inf. colliculus

Nucleus of N. IV

Optic radiation

Occipital pole
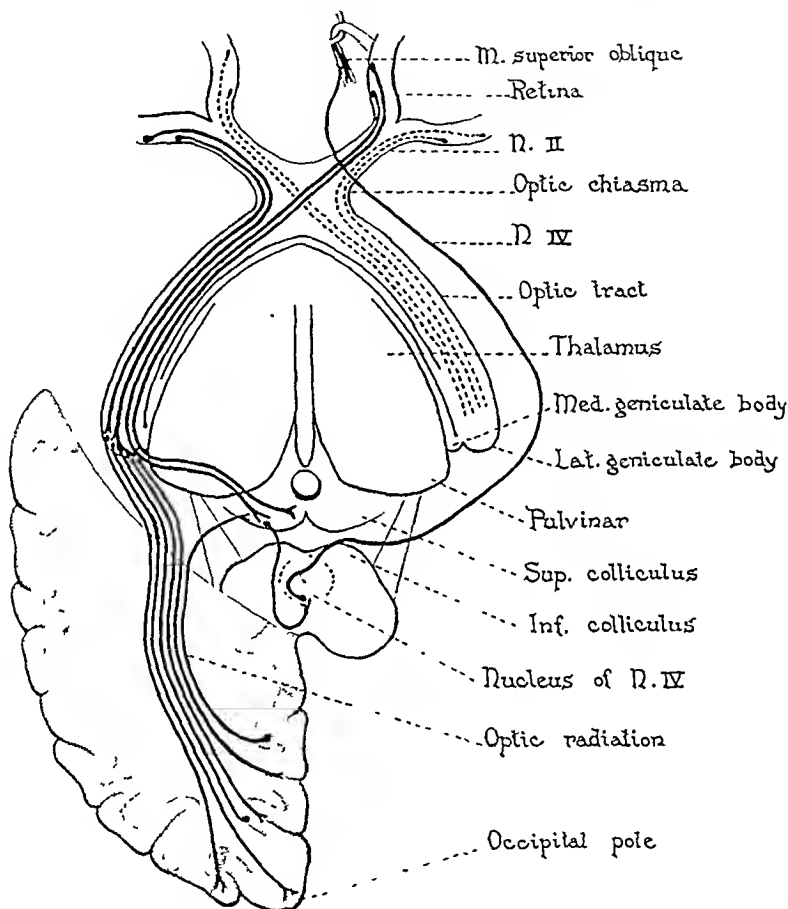
Fig. 18. Diagram of visual pathways. (Modified from Ranson.)

structure of the cranium. It is to be expected that differing types of brain damage are often seen in the same patient.

Fractures of Skull. While we know that in any large group of head injuries the mortality rate will increase directly with the number of fractures, we can never say that the fracture *itself* is the cause of death. It is more likely that the patients with fractures have received more severe be good, but the prognosis for recovery of function depends upon the cerebral area involved.

The type of skull fracture depends to a large extent upon its mode of production. When the head is struck by a relatively small rapidly moving object—a hammer, pistol butt, monkeywrench, bottle, or the flying heel of a mule—the skull is bent inward until it breaks, and a depressed

"eggshell" fracture results. When the head is struck violently against a flat resistant surface, the scalp is torn, the skull flattened until it cracks, and a compound linear fracture results. These linear fracture lines usually extend into the thinner portions of the skull either at the base or at the squamous portions of the temporal bones.

BASILAR FRACTURES. Fractures of the base are of alarming importance when they cause rupture of large vessels or when they extend into the accessory nasal sinuses or ears (compound fractures). Fractures of the base may occur at any point, but the middle cranial fossa is the weakest portion and it is here that the majority are found. Linear fractures of the base are of special clinical significance because of the frequency with which the vital structures of the brain stem are directly affected by the force causing the fracture.

Intracranial Hemorrhage. Following trauma to the head intracranial bleeding of four different types may occur. Three types involve the brain only indirectly by pressure or irritation.

EXTRADURAL HEMORRHAGE. An extradural hemorrhage of dangerous size occurs usually in the middle fossa of the skull. However, a large extradural clot is occasionally seen over the surface of the brain or in the posterior fossa of the skull. When in the middle fossa it has its origin from the middle meningeal artery. The artery is usually torn by a linear fracture extending across the squamous portion of the temporal bone. While the hemorrhage usually begins in the temporal region with the first symptoms and signs referred to this area, it may slowly or rapidly expand to fill the greater part of half of the cranial cavity. The bleeding continues in somewhat of a vicious cycle, stripping the dura mater from the skull and tearing vessels communicating between the dura and the skull.

SUBDURAL BLEEDING. Hemorrhage into the subdural space may accumulate rapidly or slowly depending upon the size of the torn vein or the degree of tearing. The hematoma may at times become large enough to produce symptoms within a few hours, but in the majority of cases days, weeks, or even months may elapse before the clot attains sufficient size to cause unmistakable symptoms. In the chronic form the collection of blood is encapsulated in a mesothelial membrane between the dura mater and the arachnoid. The chronic hematoma arises usually from veins emptying into the sagittal sinus and the original trauma may have seemed trivial.

A subdural collection of fluid, frequently referred to as a subdural hygroma, is a common and most interesting pathologic lesion. It is presumably produced by a rupture in the arachnoid so small that fluid seeps into the subdural space through the tear and becomes trapped. There being no absorptive mechanism in the subdural space, the fluid compresses the brain, producing symptoms almost identical to those produced by subdural hematoma.

SUBARACHNOID BLEEDING. The subarachnoid space through which the cerebrospinal fluid is constantly circulating is frequently contaminated with blood after trauma to the head. Usually, a massive hemorrhage results from bleeding at the base of the brain directly into the large basal cisternae. Even fresh blood in the cerebrospinal fluid is an irritant, but as the red cells disintegrate, thus forming bilirubin and biliverdin, the irritative reaction is increased tremendously and in this stage all the classic signs of meningitis may be observed.

INTRACEREBRAL HEMORRHAGE. Much has been said about petechial hemorrhages into the brain and no doubt these occur in many head injuries and may even explain many residual symptoms. Although they are most often cortical, they are far more serious when they occur in the hypothalamus or brain stem.

Occasionally, a subcortical collection of

blood is of sufficient size to produce signs of local compression as well as signs of increased intracranial pressure. This, the so-called subcortical hematoma, is not an interstitial extravasation but a localized collection of laked blood. Subcortical hematoma may also occur from bleeding into an infarcted area which is undergoing softening. The blood is often of a liquid or tarry consistency and can be evacuated through a ventricular cannula with relief of symptoms.

Injuries to Brain—CONCUSSION. When a patient receives a blow on the head of sufficient force to interrupt normal brain function he becomes unconscious. The duration of unconsciousness is often a direct reflection of the degree of injury to the brain substance. The pathologic changes in the concussed brain are still imperfectly understood—some believe concussion to be due to minute petechial intracerebral hemorrhages; others maintain that it is due to cerebral agitation with disruption of the function of the nuclear membrane and resulting abnormal interchange between nucleus and cytoplasm in the nerve cell. Concussion may be caused by accelerative, decelerative, compressive and shearing physical forces and may be associated with characteristic alterations in the normal electrical activity of the cortex.

CONTUSIONS AND LACERATIONS. These are quite different in their gross and microscopic appearances from corresponding states seen in other soft tissues. Most important, perhaps, is the relatively small amount of edema which occurs in the brain. The literature abounds with descriptions of extreme swelling of the brain from edema, yet all of the recent experimental studies indicate that this is a false conception. Furthermore, this new conception is consistent with the clinical evidence accumulated from large groups of craniocerebral injuries in which the cerebrospinal-fluid pressure is usually normal or lower than normal in the cases without gross hemorrhages. The most vulnerable points for lacerations and contusions are at the tips of the frontal, temporal, and occipital lobes. In the majority of instances greatest contusion occurs at the point of impact, but not infrequently the opposite side of the brain is contused by contra coup. The location of the lacerations and contusions is of fundamental importance. A small laceration in the hypothalamus or the brain stem usually produces ·death, whereas extensive lacerations of the· more silent areas of the cerebral hemispheres are tolerated remarkably well.

## NEUROLOGIC SIGNS

In many instances the only difference between good and bad management of a patient with a severe craniocerebral injury is the physician's ability to recognize and interpret neurologic signs. To attempt to enumerate all of the abnormal neurologic signs occurring with head trauma would require a comprehensive course in neurologic diagnosis. However, there are certain phenomena which must be thoroughly understood if the complications are to be recognized sufficiently early for adequate treatment to be instituted.

State of Consciousness. The depth and duration of unconsciousness are fairly reliable indices to the degree of brain damage. A patient who has not regained consciousness within two hours after injury has sustained contusions and lacerations of the brain and, therefore, belongs to the seriously ill group. But even the stage of primary unconsciousness may be misleading. A history of a short unconscious period followed by a complete restoration of consciousness and then a recurrence of drowsiness or stupor is one which in no circumstance can be disregarded. This, the so-called lucid interval, nearly always indicates an external hemmorhage and demands immediate exploratory craniotomy.

In the more seriously injured group,

deepening of the unconscious level may be the only indication of an extradural or subdural clot and, therefore, has the same practical significance as a true lucid interval.

The duration of unconsciousness is a helpful prognostic sign. Those who remain unconscious for days or weeks have been hurt more seriously, and, therefore, the permanent residual disability will probably be greater. However, this is not always true as many patients, particularly those in whom the major trauma is limited to the tips of the cerebral hemispheres, may remain stuporous for a period of three or four weeks, yet recover completely in the course of time.

The depth of unconsciousness is also helpful in prognosis. The patient who fails to respond to auditory stimuli and yet who makes purposeful movements with deep supra-orbital pressure is less severely injured than the patient who fails to respond to such stimuli.

Paralysis. If the patient is unconscious it may be difficult to decide whether or not there is partial or complete paralysis of an extremity. In most instances the alert observer can sit at the bedside for five minutes, observe the patient's restless movements, and determine whether or not one leg or one arm is weaker than its corresponding member. The nurse will often state accurately that the patient uses one arm better than the other. Weakness of one extremity can be demonstrated easily in a number of ways; perhaps the simplest way is to exert supra-orbital pressure first on one side, then on the other, and observe the purposeful movements of the arms. In some patients the first indication of an impending hemiplegia is an asymmetry of the facial muscles after this maneuver. In the profoundly unconscious patient, simply lifting and letting fall an arm or leg will demonstrate loss of muscle tone on the paralyzed side.

Tendon reflexes will be normal or increased in an incompletely paralyzed extremity and diminished or absent if the member is severely paralyzed. The Babinski response, when present, is a reliable guide to pyramidal-tract damage. Complete loss of plantar response indicates a greater degree of damage to the pyramidal system than does the positive Babinski sign.

As soon as it is possible to obtain the patient's cooperation, examination of the functional activity of the cranial nerves often gives valuable information. Although the olfactory, facial, acoustic, and trigeminal nerves and the nerves to the extra-ocular muscles are involved most frequently and in approximately the order given, any of the cranial nerves may be paralyzed from head trauma. Cranial-nerve palsies, if discovered immediately after the injury, have a poor prognosis for recovery because in all probability the nerve was severed by bony fragments at the moment of impact. However, if normal function of the nerve was observed early but subsequently was lost, severance of the nerve is unlikely and, therefore, recovery is probable.

Decerebrate Rigidity. Most distressing of all patients with head trauma are those in whom decerebrate rigidity develops. This state is characterized clinically by extensor rigidity; the muscles of the neck, the arms, and the legs are in a state of extreme hypertonicity. Stimulation of any sort produces waves of extensor rigidity in which the musculature seems to be in a tonic spasm. The state resembles closely the waves of hypertonicity seen in tetanus, but unlike tetanus the waves of rigidity are of short duration and are soon followed by relaxation.

The waves of decerebrate rigidity are not easily confused with convulsive movements. The differentiation from pyramidal ridigity depends upon the extensor rather than the flexor hypertonus in the upper extremities. Decerebrate rigidity indicates se-

unconscious patient *who has been placed in postural drainage* is a grave prognostic sign. It indicates a massive brain injury with medullary involvement, either directly or
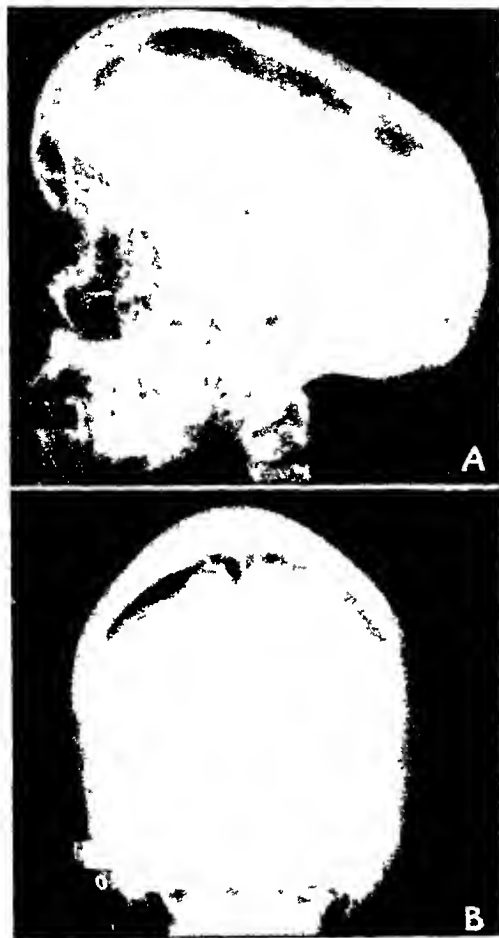


FIG. 19. Roentgenograms of skull showing a large collection of air in subdural space from a fracture extending into frontal sinuses (A) Lateral view; (B) anteroposterior view.

from pressure Changes in respiratory rate may occur with surgical lesions, particularly with extradural clots, but this is a late phenomenon and the other classic signs of the lesion have long since been in evidence.

Pulse Rate. Raising the intracranial

pressure above normal from any cause (intracerebral bleeding, extra or subdural hemorrhage, increasing the cerebral blood or fluid volume) is accompanied by a gradual slowing of the pulse rate. Only when the pressure has become elevated to a point where medullary function is impaired does the pulse rate become rapid. A rise in pulse rate, therefore, when the rate has been slower than normal, is a sign demanding immediate active measures designed to relieve increased intracranial pressure.

Blood Pressure. As intracranial pressure increases acutely, the blood pressure, likewise, increases, that is, until medullary failure supervenes, when the blood pressure falls rapidly. A mounting blood pressure associated with a slow pulse is a positive indication for treatment to reduce the intracranial pressure Basilar injuries, particularly in the region of the hypothalamus or medulla, are associated with a marked rise of blood pressure, but in these lesions the pulse rate is almost always rapid from the beginning. A slowly rising (two or three days) intracranial pressure rarely raises the blood pressure.

Temperature. A rise of temperature usually means brain-stem or hypothalamic irritation, from either direct trauma or irritation from blood. A high temperature in the acute stage of head trauma is a grave prognostic sign and usually indicates damage to medullary structures. Fever, appearing late in the course of the illness, however, may be due entirely to the irritative reaction of decomposed hemoglobin in the cerebrospinal fluid or even to secondary pressure on the brain stem from increased intracranial pressure

Ocular Signs. Careful observations of the state of the pupils, particularly as regards their size and responsiveness to light, are most important in recognizing the complications of head trauma A unilateral dilated fixed pupil is pathognomonic of either an extradural clot on the same side or mas-

sive contusion and laceration of the cerebral cortex on the same side. Bilateral dilated fixed pupils are seen only in hopelessly injured patients with massive brain destruction or in the last stages of an extradural clot. In the former condition they have no surgical significance. In the latter, *providing there is a clear-cut history of the* dilatation being unilateral in the beginning, an attempt to remove the clot should be made.

Pupils constricted to a pinpoint in which there has been no morphine administered are indicative of pontine or brain-stem injury. In the last stages with lesions in this location the pupils become widely dilated and fixed.

Early examination of the eyegrounds is of little value except in the severely injured group. Retinal hemorrhages within a few hours after injury indicate massive lacerations and contusions of the brain and the patient, therefore, has a grave prognosis. Elevation of the optic disks (choked disks, papilledema) later in the course of the illness has the usual significance of increased intracranial pressure and may be seen with any of the complicating lesions of head trauma producing this state.

Unilateral or bilateral exophthalmos usually indicates hemorrhage into the orbit from fractures involving the frontal fossa. Such cases are always complicated by ecchymosis of the soft tissues of the orbit and eyelids. Rarely, exophthalmos may be due to an occluded cavernous sinus from trauma or from an arteriovenous fistula between the carotid artery and cavernous sinus. In such circumstances, the exophthalmos and edema are out of all proportion to the degree of ecchymosis.

Vertigo. Basilar fractures of the skull which involve the petrous pyramid very frequently produce alarming degrees of vertigo. Each time the patient is moved he complains of violent dizziness and may clutch the bed because he feels as if he were going to be hurled from it. Violent nausea and vomiting often accompany these attacks of vertigo. During the episode, sustained nystagmus is usually observed regardless of the direction of the gaze. After acute symptoms have subsided, many of these patients remain dizzy, especially with changing positions of the head. In this group the sodium-poor diet with ammonium or potassium chloride administration is usually effective in relieving the vertigo.

Mental Symptoms. The restless delirium frequently seen with acute head injuries is an outward manifestation of cerebral trauma, particularly trauma at the tips of the frontal and temporal lobes. This state usually subsides as cerebral healing progresses. Complete orientation gradually occurs over a period of several days, but ordinarily the patient has complete amnesia extending from a variable period prior to the accident (retrograde amnesia) to the time of regaining consciousness.

In the severely injured group memory defects and often personality changes may continue for months, and in many cases are permanent. When the contour of the brain of these patients is studied by encephalography one wonders why there is not more profound deterioration than is shown clinically.

In the moderately or slightly injured group the presence of personality changes, memory defects, and bizarre behavior of any type may have especial significance for such changes are most constant findings in chronic subdural hematoma. Every patient having persistent personality changes of any degree should be subjected to diagnostic air studies.

## TREATMENT

Inflexible, routine treatment of patients suffering from head trauma is not only useless but dangerous; no other group of surgical patients demands such individual

consideration. Excellent therapy for one patient may be poison to another; yet the two patients, to superficial examination, are not unlike in their clinical manifestations. Alert, watchful care is perhaps the most important feature. Since the patient's condition may vary from hour to hour, continuous efficient nursing care is of prime importance.

For the sake of convenience, this section is divided into (1) nonoperative treatment and (2) operative treatment. The principles for the general care of patients who are operated upon apply equally well to those who receive conservative treatment.

## NONOPERATIVE TREATMENT

Traumatic Shock. The symptoms of traumatic shock are observed infrequently in the uncomplicated case of head trauma. As a matter of practical importance, if the patient is in shock when first seen one-half to one hour after injury, one should be careful in seeking for other injuries—a broken neck, a fractured femur, or a ruptured viscus with intrathoracic or intraperitoneal hemorrhage.

When signs of surgical shock are observed, the treatment of shock takes precedence over every other consideration.

The common practice of rushing unconscious patients to the x-ray room for head films is dangerous if used routinely. Skull roentgenograms may be almost indispensable for diagnosis in some cases but certainly in the vast majority of head injuries the x-ray examination contributes no important data during the acute phase of the illness.

When roentgenograms are indicated it is essential that the nurses, orderlies, and x-ray technicians understand the elementary dictates of first-aid care. Rough handling of the patient in transferring him to the x-ray table is undoubtedly responsible for many deaths. Portable x-ray equipment has reached such a high degree of perfec-

tion that bedside roentgenograms of the head may be eminently satisfactory.

In depressed fractures of the skull, roentgenograms are invaluable, but in most instances the diagnosis of depressed fracture is made by knowing the type of object striking the head and, more important, by palpating the skull through the scalp wound. When extradural hemorrhage is suspected, a linear fracture through the middle meningeal groove is useful evidence. When the fracture extends into the accessory nasal sinuses an x-ray examination may rarely disclose air in the ventricles or the subarachnoid space, thereby giving information which may be imperative in the proper management of the case. However, these are matters which are of importance only when surgical intervention is contemplated and never during the primary treatment of the unconscious patient. With the compensation laws as they are today it is necessary that roentgenograms be a part of the record for legal purposes. X-ray examination, therefore, should always be made after the patient has passed the critical stage of his illness.

Restlessness. Extreme restlessness is a disturbing early complication of head trauma. If it is only of mild degree, simple nursing measures are sufficient. When extreme restlessness is encountered, it becomes necessary to use sedative drugs. The time-honored practice of giving morphine to restless patients is dangerous unless it is given in very small doses. As a matter of fact, in certain basal injuries in which the hypothalamus or brain stem is affected, morphine in tiny doses ($\frac{1}{60}$ to $\frac{1}{30}$ gr.) is a valuable therapeutic adjunct. However, the customary dose of $\frac{1}{4}$ to $\frac{1}{2}$ gr. is very dangerous because of the depressing effects upon the respiratory centers.

Paraldehyde is, perhaps, the best available drug to quiet the restless patient. It may be given by mouth, by rectum, or by vein. The latter method is indicated only in

the extreme case in which other avenues are impossible. A mixture of bromides and chloral is also a safe sedative in head trauma. The barbiturates, unless given in very large doses, are not effective, and in many cases seem to add to the excitability of the patient. Extreme restlessness may last for several days and in treating this group of patients it is best to let them thrash about the bed under restraint for at least half of each 24-hour period.

Nourishment. Adequate nourishment is always a problem in the unconscious patient. Intravenous dextrose is adequate for one or two days, but if unconsciousness persists protein deficits must be supplied by gavage A basic caloric intake should be maintained throughout the illness and the usual vitamin deficiency should be supplemented.

When feeding by gavage is desirable, the nasal tube should be left in place for 12 hours and a high-caloric, well-balanced intake given. The author prefers to remove the tube each day, because "fighting the tube" is a common practice with restless patients.

Fluid Intake. The optimum fluid-intake level is a moot question. In some clinics severe dehydration is practiced. Not only is all fluid intake withheld but further dehydration is accomplished by magnesium sulfate orally and rectally and by hypertonic dextrose solutions intravenously. The proponents of this method justify it by assuming that the control of intracranial pressure is the major consideration in the treatment of head trauma and that it is effectively accomplished in this manner.

Other observers believe that this radical form of dehydration is not only unnecessary in the majority of patients but is often positively harmful. To this point of view the author subscribes. The principle of dehydration is founded upon the fallacy that most patients with head injuries suffer from increased intracranial pressure. There has been accumulated a vast amount of data, experimental and clinical, which indicates that the intracranial pressure in the acute stage of injury is seldom greatly elevated and is often normal or lower than normal In the author's clinic a high spinal-fluid pressure is considered valuable evidence favoring a surgical complication—extradural, subdural, or intracerebral clot.

Under average conditions a fluid-intake of 2,000 cc. per 24 hours is recommended It is wise to consider the individual needs of the patient and the influence of temperature and humidity upon fluid requirements In the unconscious patient fluids are best supplied intravenously as 5 or 10 per cent dextrose—the first 1,000 cc. as 5 per cent dextrose in Ringer's solution and the second 1,000 cc. as 10 per cent dextrose in distilled water. Ten per cent dextrose should be given very slowly or else the sugar will be spilled into the urine. With prolonged unconsciousness the 2,000-cc. fluid level is maintained by gavage.

Spinal Puncture. There is a wide variation in opinion regarding the usefulness of cerebrospinal-fluid withdrawal in the treatment of acute head trauma. Some observers maintain that the practice is dangerous, while there are those of equal authority who contend that spinal-fluid drainage is one of the most valuable therapeutic measures.

There is little doubt that the dangers of lumbar puncture in head trauma have been overemphasized; in fact, in some clinics the aversion to the procedure borders on the superstitious. To reach a decision in regard to spinal puncture one must study the effects of withdrawal of lumbar cerebrospinal fluid.

If the initial pressure either in the supratentorial or the infratentorial fossa is high, sudden withdrawal of fluid from the spinal subarachnoid space may precipitate a pressure cone—at the incisura in case the supratentorial pressure is higher and at the

foramen magnum in case the subtentorial pressure is greater. Pressure cones may result in immediate death or alarming increase of medullary symptoms. These accidents occur usually when the spinal fluid is withdrawn rapidly and in large amounts and are uncommon in patients who have a reasonable chance of survival.

CONTRAINDICATIONS. In the absence of increased intracranial pressure spinal puncture should be an exceedingly safe procedure. The contraindications to lumbar puncture in head trauma are as follows: (1) Clinical evidence of high intracranial pressure; (2) clinical signs pointing to an expanding lesion in the posterior cranial fossa.

As a diagnostic procedure lumbar puncture is invaluable. When the clinical signs of increased intracranial pressure are equivocal, spinal manometric readings yield invaluable information. Diagnostic lumbar punctures are performed with a small needle, and not more than a few drops of fluid are lost while the pressure readings are being made. Also, observing a drop of the fluid gives some index as to the amount of blood it contains. While the number of red cells in the cerebrospinal fluid is *not* an accurate index to the degree of brain damage, it does indicate the degree of meningeal irritation which may be expected later in the convalescence. One word of warning—never perform the Queckenstedt test in the course of a diagnostic lumbar puncture on a patient with a craniocerebral injury! This maneuver increases the danger and yields no valuable information. This test is useful only when a spinal subarachnoid block is suspected.

As a therapeutic measure spinal puncture is of little or no value and may be harmful in acute head trauma. By therapeutic lumbar puncture is meant the drainage of cerebrospinal fluid in sufficient amount to change the volumetric relationships within the skull. The proponents of this method of treatment advise draining fluid until the spinal-fluid pressure registers 50 to 100 mm. The theory that drainage promotes a more adequate blood supply to the brain is open to question. If an extradural, subdural, or intracerebral clot is suspected, and the diagnostic spinal puncture shows the pressure to be high, one should *never* be tempted to drain fluid to reduce pressure, for a sudden fatality may result.

There comes a time, however, in many cases of head trauma, when therapeutic lumbar punctures are exceedingly valuable. Blood in the cerebrospinal fluid is an irritant and, after hemorrhage has ceased and the contaminated blood is being absorbed, irritative meningitis is often a serious complication. Spinal drainage at this stage of meningeal irritation relieves symptoms dramatically. The procedure should be repeated once or twice daily until the fluid is almost free of color. There is considerable evidence to indicate that the late drainage of blood-contaminated cerebrospinal fluid may be valuable in preventing posttraumatic sequelae.

Hypertonic Solutions. The routine use of hypertonic solutions in acute head trauma is a practice which cannot be condemned too severely. This form of would-be therapy has gained alarming popularity. When one inquires as to the treatment the patient has already received, too frequently there is the reply, "A spinal puncture and 100 cc. of 50 per cent glucose intravenously." The mild head injuries get it; the severe basal injuries with cerebrospinal fluid leaks get it; even the extradural and subdural hematomas get it; in fact, every unconscious patient after head trauma will often have been given hypertonic dextrose solutions intravenously during the first 24 hours. Fortunately, intravenous hypertonic glucose is tolerated remarkably well by these patients and prob-

ably very few gain or lose their lives because of it.

There is a distinct place, however, in head therapy for intravenous hypertonic solutions. They ·may be of great value in temporarily reducing intracranial pressure in desperately ill patients with surgical complications while the operating room is being prepared. Also, there is a relatively larger group of patients who on the second to fourth day of their illness develop meningeal irritation with high intracranial pressure. In this group, judicious use of hypertonic solutions is beneficial.

Care should be exercised in the selection of the hypertonic solution, for each has certain advantages and disadvantages. Hypertonic sodium chloride is perhaps the most efficient one of the group for immediate reduction of intracranial pressure. However, the action is short and the drug accumulates in all soft tissues of the body before it can be excreted, and a secondary wave of edema results. Concentrated dextrose has a similar action with respect to the physical properties of the solution. Either of these drugs may be used to advantage when it is desirable to relieve suddenly the intracranial pressure (as when an extradural clot is awaiting surgery).

When prolonged reduction of pressure is desired, hypertonic sucrose (50 per cent) possesses certain advantages. Sucrose is not metabolized; therefore, it is excreted as sucrose. It is excreted slowly, and the dehydrating effect is prolonged. It is not collected in the soft tissues, hence, there is no secondary wave of edema. This drug is not without danger for renal damage of severe grade has been demonstrated in patients after prolonged administration.

Dehydration by magnesium sulfate administered by the gastro-intestinal tract makes an already difficult nursing problem more difficult, and the therapeutic value is no greater than that of sucrose given intravenously. Recent Army experience with concentrated albumen in 25-Gm. units indicates that this dehydrating agent is effective for that primary function and causes no undesirable sequelae.

Postural Drainage. If the blood pressure is normal or higher than normal the head-up position is desirable for the first few hours to discourage venous bleeding. But if the conscious level is so low that the gag reflexes are diminished or abolished, saliva and secretions from the nasopharynx drain into the bronchial tree in an endless stream. When the patient's respirations become rapid and noisy and his color cyanotic, it is too often concluded that his lungs are filling up from a failing circulation. The unconscious patient from any cause seems to have an excess amount of mucoid and salivary secretions. Perhaps the oversecretion is due to vagal paresis; certainly, in all patients with vagal involvement this unusual flow of bronchial mucus seems to occur. The horizontal position, particularly if the patient is on his back, is almost as bad as the up-right position.

A large accumulation of mucus (or blood) in the bronchial tree impedes free respiratory exchange and interferes with aëration of the circulating blood. As a consequence, anoxemia of all tissues of the body, including the brain, develops. When anoxemia is superimposed upon an already damaged brain, the impending tragedy is not long delayed. The customary use of the oxygen tent or oxygen tube is not effective if there is mechanical impediment to the free flow of gases in the respiratory passages.

Postural drainage is perhaps the most important single contribution to the subject of head trauma in the past decade. The foot of the bed is elevated by whatever means available until the plane of the bed forms an angle with the floor of not less than 30°. The patient is placed on his abdomen or side so that the upper trachea,

nasopharynx, and mouth are in a position to permit the drainage of secretions by force of gravity. Patients who are cyanotic from imperfect aëration and who have labored, difficult respiration often breathe quietly and easily and regain normal color within a few minutes after correct postural drainage is instituted. A deeply unconscious patient may be changed from side to side, always keeping the corner of the mouth in a dependent position. This head-down position does not seem to embarrass the general circulation.

## OPERATIVE TREATMENT

Essential Neurosurgical Equipment. Certain special equipment, not usually found in the general surgical set-up, is required for operations upon the skull and the brain.

Outstanding among these necessary items are an adequate suction apparatus, an electrosurgical unit, silver clips, and bone wax. Their use, as well as other details regarding equipment, hemostatic methods, and technical procedures, has been discussed in Chapter 1.

Scalp Wounds. By far the most frequent complication of head trauma is laceration and contusion of the scalp. Many practitioners regard scalp wounds as trivial, but certainly this is a very dangerous point of view. Protracted illness and even death may result from improper care of a simple scalp laceration. Improper treatment of the wound means infection in at least 20 per cent of cases. An infected scalp wound often progresses to osteomyelitis of the skull; osteomyelitis of the skull is complicated by abscess of the brain and meningitis in many instances. Therefore, the only treatment for a lacerated scalp is to make every effort to prevent infection by meticulous débridement and careful primary suture.

Before the days of chemotherapy the best surgical care of the lacerated scalp, if initiated within 12 hours after the injury, resulted in primary healing in certainly 85 or 90 per cent of cases. Now by applying the same principles plus chemotherapy, infected scalp lacerations are seldom seen. However, chemotherapy must never be an excuse for lax surgical technic.

The emergency care of scalp wounds is of primary consideration. The scalp is richly supplied with blood vessels, and hemorrhage from the gaping wound may be so severe that shock from hemorrhage supervenes. Special bandages, properly applied, will control hemorrhage from almost any scalp wound no matter how extensive. Therefore, all first-aid kits should contain sterile gauze rolls to be placed between the gaping edges of the wound. Then a tourniquet type of bandage should be applied in such a manner that direct pressure is made upon the gauze rolls. Knitted elastic bandages are superior to the gauze type for this dressing. Before placing the gauze packs sulfanilamide powder should be dusted into the wound unless the patient will receive complete surgical care within an hour or two. Sulfanilamide powder does not delay healing, and the antiseptic property is exceedingly effective upon most micro-organisms.

When the patient with a scalp wound reaches the hospital or the first-aid station the following surgical routine should be practiced:

1. The scalp should be shaved cleanly for a distance of two or three inches around each margin of the wound. If the laceration is a large one, the entire head should be clipped and the area around the laceration shaved carefully. The shaving should extend well up to the wound margins so that all possible hair is removed. Do not worry about contaminating the wound with the shaving technic.

2. Procaine block anesthesia of the entire area to be operated upon is accomplished by placing a series of novocaine

wheals at strategic points about the scalp wound. Infiltration with 1 per cent procaine between these points blocks all sensory impulses from the area and permits painless repair of the wound Preparation of the scalp for novocainization is accomplished with the usual surgical routine for clean cases This is accomplished by scrub-

cleansed thoroughly by scrubbing with green soap and water. All blood clots, débris, hair, etc, should be carefully removed. Bleeding points should be controlled with small hemostatic forceps or with electrocoagulation The skull and pericranium should be carefully inspected and palpated for fractures. *Débridement is then*
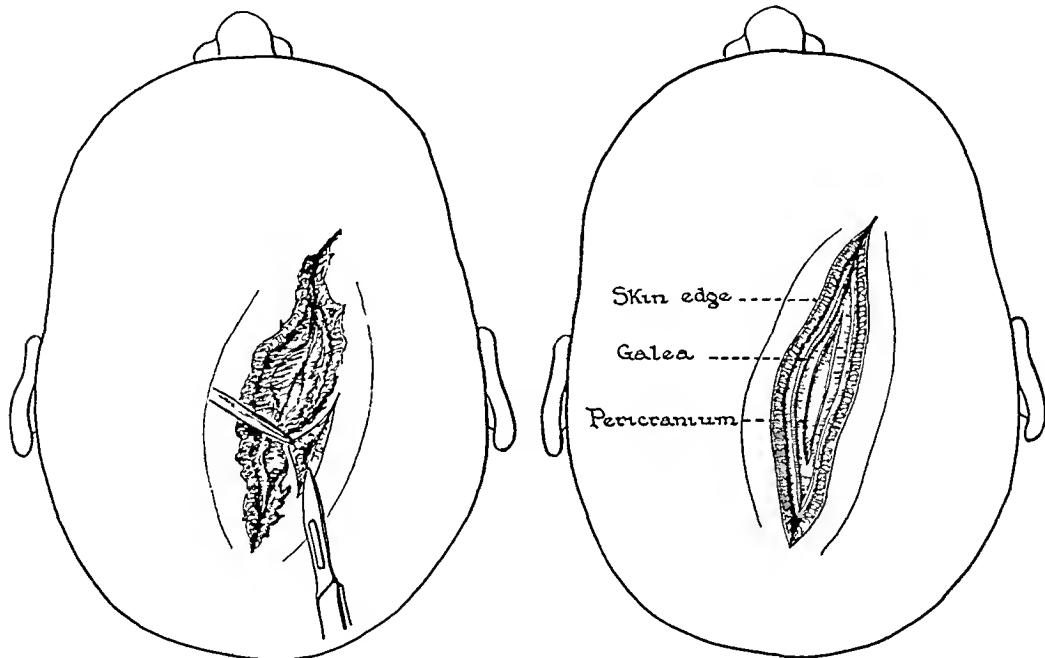


FIG. 20. (*Left*) Diagram illustrating method recommended for excision of jagged edges of scalp laceration.

FIG. 21. (*Right*) Diagram illustrating appearance of a completely débrided scalp wound.

bing the scalp with three series of 70 per cent alcohol sponges followed by three series of sponges in 1 1,000 bichloride of mercury. Frequently, the entire area is painted with tincture of merthiolate. The most scrupulous care should be taken to prevent antiseptic drugs from coming in contact with the open wound. Strong antiseptics kill living cells and, therefore, further devitalize the damaged tissue

After novocaine block anesthesia is completed, the head is draped in the usual manner, after which surgical care of the scalp wound is started. First, the wound is

started from the bottom of the wound. If in doubt as to the viability of tissue, it should be removed until active bleeding from its edges occurs. Then the edges of the scalp wound itself are cleanly excised and hemorrhage from the normal tissue is controlled with hemostatic forceps applied to the galea (Fig. 20). If the wound is jagged or stellate, great ingenuity may be necessary to effect approximation of the edges without excessive tension If the wound-edge tension appears too great, it may be relieved by straight incisions to either side and parallel to the wound. Of course, care-

ful hemostasis must be secured in the new wounds, for they are not sutured.

As soon as débridement is completed (Fig. 21), 1 or 2 Gm. of sulfanilamide powder (in ampule) are dusted into the wound and spread throughout. Sulfanilamide in some instances appears to act as a hemostatic agent and in others bleeding appears to increase after its application. At any rate, the most scrupulous care is necessary in drying the field.
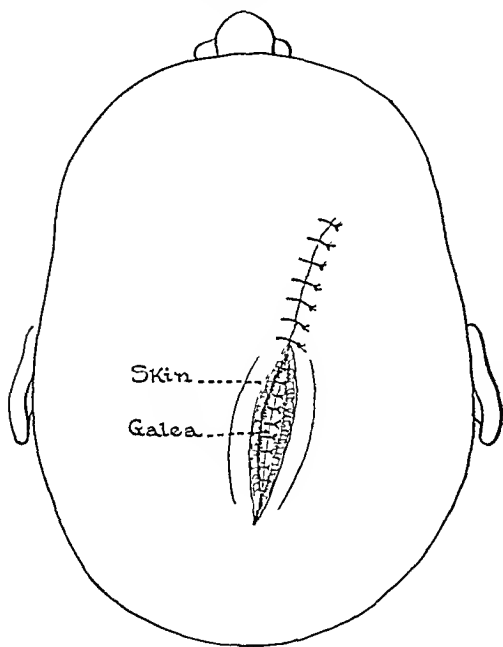


Fig. 22. Diagram illustrating technic of two-layer closure of scalp wounds with black silk after complete débridement.

Electrosurgery is a splendid adjunct in all operations about the head. However, it must be used with great care. If large portions of tissue are coagulated, the resultant slough will prevent primary wound healing. Each little bleeding point should be isolated and a minimal amount of cutting current used to seal the blood vessel.

Closure of the wound is accomplished in the following manner: First, interrupted fine silk sutures are used to approximate the galea aponeurotica. By placing a suture at a point where bleeding has been controlled with a hemostat, the bleeding vessel is incorporated in the knot when the suture is tied. Then through-and-through stitches of silk are made on either side of the galeal stitch (Fig. 22). Tension in tying the through-and-through scalp stitches should be avoided or a superficial slough may occur. When the closure is completed, the wound should be flat with no accumulation of blood beneath it. If blood has accumulated in sufficient quantity to elevate the wound the drying process has been incomplete and the whole wound should be reopened and more complete hemostasis secured. In no ordinary circumstances should a drain be left in a scalp wound. Draining a scalp wound is an acknowledgment on the part of the surgeon that he is incapable of drying a wound properly. In addition, the drain provides a perfect avenue for infection to travel from without to within the wound. After closure is complete silver foil is placed over the edges of the wound and the usual head dressing is applied.

**Fractures of Skull.** In most patients who have had head injuries, whether or not the skull is fractured is of relatively minor importance. It is true that in a large series of cases the group in which the skull is fractured will have the highest mortality rate. In other words, fracture of the skull represents, roughly, the degree of trauma to which the head has been subjected. Only certain types of skull fractures have operative implications. All depressed fractures, whether simple or compound, demand operative interference at the most opportune time in the illness if the depression is of significant degree. A few of the linear fractures may demand operative treatment, particularly those which extend into the nasal accessory sinuses or the ears and those which cross the groove of the middle

meningeal artery in the temporal bone
However, in this latter group the indications for surgery are relatively infrequent

DEPRESSED FRACTURE OF SKULL. When the head is struck by a relatively small, rapidly moving object (i e. a hammer, pistol butt, monkeywrench, bottle, or flying heel of a mule) the skull is bent inward until it breaks, and a depressed "eggshell" fracture results  The scalp may or may not be broken at the site of impact; if it remains

wound is thoroughly débrided as described under the treatment of scalp wounds, the broken pieces of bone are removed, the torn meninges carefully repaired, and the contused, devitalized brain tissue removed cleanly with suction. In this type of case improper treatment may cause infection with all its dangers and often result in a cortical-meningeal-scalp scar which sooner or later produces convulsive seizures (traumatic epilepsy). Furthermore, if proper
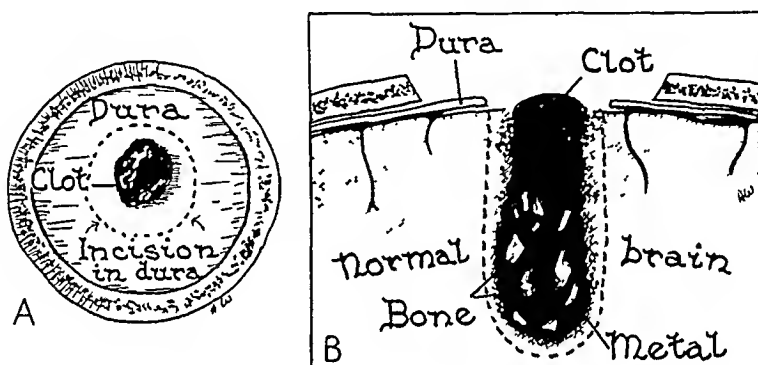


FIG. 23. Diagram of operative steps in penetrating wounds of brain. (A) Skull has been rongeured to provide a smooth circular opening. Clot is shown extruding from torn dura mater. (B) Dotted line indicates area of contused brain, blood clots, and bone fragments to be removed  (Modified from Horrax.)

intact, the fracture is called a simple depressed fracture and if it is lacerated through the pericranium, the lesion is described as a compound depressed fracture  Whether simple or compound, the indication for surgical repair of the depressed bone fragments is clear

Depressed skull fractures are usually associated with meningeal tears and localized brain damage  But in injuries of this type the damage to the brain is usually local contusion and laceration. Therefore, prolonged loss of consciousness and the other signs of diffuse brain damage are usually lacking  Depressed fractures of the skull comprise approximately 5 per cent of the head trauma cases. Treatment of this type of injury is purely mechanical  The scalp

treatment is afforded this type of case in the beginning, epilepsy will develop in fewer instances. This lesion is without doubt the most important problem in military neurosurgery, and unless the principles of treatment are standardized and followed carefully, many epileptic veterans will haunt us for the next two decades

Débridement of the wound is started from without inward, following the technic used for scalp lacerations, until the skull is reached  Then the fragmented portions of skull are removed and the bony edges rongeured away until a smooth defect remains  Bleeding from the bone is controlled with wax, but all excess wax must be removed

The care of the dural tear is an important step. If the dura has been fragmented

and direct closure cannot be made, then the defect should be patched either with fascia lata or preserved animal membrane (Cargile's membrane). This, of course, is not attempted until the contused brain has been débrided. Bleeding from the surface or the substance of the brain cannot be controlled satisfactorily except with electrosurgery, silver clips, muscle implants or fibrin foam.

Many surgeons advise saving the bone fragments and attempt to prop them against each other for the repair of the skull defect. This practice is not recommended for two reasons: (1) Adequate support for these fragments after the scalp is closed snugly above them is not available. If the bony fragments sag into the defect a scar will form between the fragments and dura mater and perhaps the cortex, and the purpose for which radical surgery was instituted in the first place will have been defeated. (2) The repair with loose bony fragments usually results in an irregular unsightly scar.

In the author's experience it is preferable in most instances to remove the fragments completely and repair the skull defect at a later date with a tantalum plate. The cosmetic result of such a repair is infinitely superior and the danger of a cerebral cicatrix is greatly reduced. At least three or four weeks from the original trauma should elapse before the repair is attempted.

Depressed fractures of the skull which are not compounded are handled exactly in the same manner as indicated above. In such circumstances a circular flap of the scalp is laid back over the depressed fracture and the same routine followed in repairing the skull, the meninges, and the traumatized brain.

FRACTURE OF SKULL INVOLVING PARANASAL SINUSES. Linear fractures of the skull frequently extend into the paranasal sinuses, particularly the ethmoids and fron-

tals. These linear fractures are of added importance because they may expose the brain to infection. In the majority of instances, the only outward sign of this complication is bleeding from the nose or into the nasopharynx. During the first few hours it is often difficult to determine whether there is cerebrospinal fluid mixed with the bloody nasal discharge, and since most of the fistulae close spontaneously within 12 hours, the occurrence of cerebrospinal-fluid rhinorrhea is perhaps more frequent than is generally supposed. These fracture lines are difficult to verify with roentgenograms; hence a negative x-ray report when the patient has discharged blood or blood-tinged cerebrospinal fluid from the nose should be disregarded. But roentgenograms are particularly important in these cases for they may show, in subarachnoid space or ventricles, air which has been aspirated through one of these small nasal fistulae (Fig. 19). Chemotherapy should be instituted immediately if such a complication is even suspected.

Cerebrospinal-fluid Rhinorrhea. Occasionally, fracture into the ethmoid sinus may not produce rhinorrhea until late in the illness, and it may occur even weeks after recovery is considered complete. The presumption is that a small dural laceration seals itself off during the acute illness only to be reopened later by forcibly blowing the nose or by sneezing violently. Also, in these delayed cases air may be aspirated and pneumocephalus develop. There is danger of meningitis in the delayed as well as in the acute cases, and the treatment implications are the same.

Meningitis complicating head trauma is, in the vast majority of instances, due to linear fractures of this type. The treatment problem, therefore, is two-fold: First, stop the cerebrospinal-fluid leak, and second, discourage infection by chemotherapy.

Fortunately, most fistulae close spontaneously and, therefore, no specific surgical

treatment is indicated. In no circumstances should antiseptic solutions be instilled into the nose. These patients require rather profound sedation to discourage coughing, sneezing, and straining—the results of which may aspirate infected material into the cranial cavity. Chemotherapy should be started immediately.*

A cerebrospinal-fluid fistula that persists for longer than 48 hours should be repaired surgically if the patient's general condition permits a surgical procedure.

While it is true that the fistula may close later, the chance of recurrent cerebrospinal-fluid discharge and ever-present danger of meningeal infection make operative repair of the torn meninges the safest and surest method of handling this troublesome situation. In the author's series of head-trauma cases there have been two deaths from delayed meningitis—one after 9 months and the other 18 months after what appeared to have been complete primary closure of the cerebrospinal-fluid fistula.

Before planning a surgical approach, accurate knowledge of the site of the meningeal tear is essential. This can usually be determined fairly accurately from careful study of the stereoscopic roentgenograms. The tear is usually close to the cribriform plate and, therefore, it is necessary to approach it from above. This is accomplished through the usual transfrontal approach, the small bone flap being placed quite low in order to avoid excessive traction on the frontal lobe. A generous piece of fascia lata should have been previously excised. Once the tear in the dura mater has been located, the fascial transplant is placed over the tear and the frontal lobe is allowed to fall back in place above it. It may or may not be possible to suture the transplanted fascia, but in any event the weight of the frontal lobe will usually seal the meningeal tear against the fascia.

* For details regarding chemotherapy, see Chapter 20.

This is a formidable operation, and it is recommended that the occasional intracranial operator avoid it.

A cerebrospinal-fluid leak from one or both ears has the same serious implications as from the nasopharynx, except that a fistula from the ear always closes although it may take a week or more to do so. The same principles of treatment apply as with fluid leaks from the nasopharynx. Sterile cotton plugs may be placed in the external canal and changed every hour or so as they become saturated with fluid. In no circumstances should the external auditory canal be syringed or have antiseptic drugs put into it.

Not infrequently a blood clot forms in the middle ear. Otoscopic examination will disclose this occurrence and the clot should be evacuated by puncture if any bulging of the eardrum occurs. The treatment of these complications is greatly facilitated by the close cooperation of the otologic surgeon.

**Compound Depressed Fractures of Frontal Bone.** These frequently involve the frontal sinuses. Fragmentation of the walls of the sinus with concomitant laceration of the meninges over one or both frontal lobes is not infrequently seen. These injuries are usually produced by blunt objects which shatter the thin bones of the face and sinuses like an eggshell. If these cases are treated early and adequately, chances for recovery are excellent. The same operative principles apply here as with other depressed fractures. All contused brain tissue should be removed with suction and complete hemostasis secured. The lacerated dura mater must be completely closed either by direct suture or with fascial transplant; the mucous membrane of the sinus must be completely excised and the opening into the nasal cavity coagulated with electrosurgery. Of course, sulfanilamide powder should be dusted into every corner and crevice of the wound ex-

ternal to the dura mater. Drainage through the scalp incision should never be used. If drainage is deemed necessary it should be accomplished through the nose but in no instance should the drain be in contact with the dural repair.

## PENETRATING WOUNDS OF BRAIN

Penetrating wounds of the brain in civil life are of relatively infrequent occurrence. The same type of wound so common today in modern warfare is perhaps the livest of all neurosurgical topics. The basic surgical principles established in World War I are still sound today; yet chemotherapy has radically changed some phases of the problem. Before chemotherapy, prevention and treatment of infection were the foremost considerations. Now with the proper drug of the sulfonamide group applied in the wound and given by mouth, or, as our experience grows, with penicillin, the ravages of infection are reduced to a minimum and the main surgical consideration can be directed to the best possible restoration of function. Operations upon the brain are tedious, time-consuming affairs, and are most successful when performed in hospitals away from the active combat zone. Therefore, the problems for advanced stations insofar as brain wounds are concerned are: First, control of hemorrhage; second, the judicious application of chemotherapeutic drugs, and third, evacuation of the patient to the rear as speedily as possible.

In the manual prepared for the Army Medical Corps under the direction of a committee from the National Research Council headed by Dr. Gilbert Horrax, the following pertinent statement is made:

It must be remembered by all those concerned with handling the wounded in warfare that it is their prime objective to do everything for the greatest good for the greatest number, and thus to return the highest percentage of men to active duty. In times of great stress cases must be selected for opera-

tion on this basis, but it must be borne in mind always that it is better and more profitable to do complete and careful operations, even if fewer, than to do a large number of incomplete ones since the complications and end-results of the latter are far worse.

In following this sound dictum during periods of great stress it is necessary that careful neurologic examinations be made in order that patients be selected for operation in proper sequence. As an example, a depressed fracture with no neurologic deficit would properly take precedence over an extensive brain wound with severe physiologic disturbances.

Gunshot or shell-fragment wounds of the head are conveniently divided into (1) scalp wounds, (2) scalp and skull wounds, and (3) penetrating wounds of the brain. The principles of treatment of all these groups are the same no matter what the environment may have been when the wounds were inflicted. Contamination of the wounds is taken for granted; therefore, certain prophylactic considerations are important.

All soldiers going into action should have closely cropped hair because in the event of a head wound the problem of surgical care is tremendously simplified. The first-aid treatment of the wound is simplified, especially the application of sulfa drugs and the control of hemorrhage. Also, the wound can be prepared for surgical repair more quickly and efficiently. Perhaps most important, if the missile penetrates the head deeply, débridement is much simpler if there is no long hair driven into the depths of the brain.

All soldiers, of course, should have been previously immunized with tetanus toxoid. Immunity lasts for from six months to five years, and this efficient prophylaxis practically eliminates one of the greatest horrors of war wounds.

Each soldier should be thoroughly educated to the dictum that "a scalp wound

may mean a skull fracture or even a fragment of steel in the brain." A scalp wound so small as to be missed by casual examination may be the point of entrance of a bomb fragment lodged deeply within the brain. Every scalp wound, therefore, no matter how seemingly trivial, should be reported to the nearest first-aid station.

The treatment of scalp wounds and depressed fractures of the skull has been discussed in preceding paragraphs (pp. 43–50). The principles of treatment are the same no matter in what environment the wounds were inflicted.

High-velocity projectiles (whether bullet, shell, or bomb fragment), produce characteristic destructive lesions in the head. If the missile strikes on edge the scalp wound is usually a clean perforation with minimal destruction of tissue. The skull injury is usually a circumscribed hole without linear fractures radiating from it. The hole in the outer table is not much larger than the missile, but the inner table is usually shattered with fragments of loose bone carried deeply into the brain. These bony fragments cause large gaping defects in the dura mater with destruction of cortical vessels and brain substance over a wide area. The tearing of cortical and subcortical vessels may result in intracerebral or extracerebral hematomas of varying size. The general effect, therefore, is the production of a fan-shaped area of destruction out of all proportion to the appearance of the external wound.

If the same missile strikes with its flat side against the head it produces a large jagged scalp wound with multiple radiating lacerations. The skull is "caved in," and the underlying brain destruction depends upon the velocity with which the fragment struck. In these large compounded wounds liquefied brain tissue will usually be found to herniate through the skin defect with blood-tinged cerebrospinal fluid dripping from the wound. What may be most astounding is that many patients with extensive brain wounds remain conscious.

Preliminary treatment of these wounds is extremely important. At the receiving station hair about the wound should be clipped and shaved cleanly for at least two inches about each margin. Any large bleeding vessel in the scalp should be crushed with a hemostat unless firm pressure with a roll of gauze secures complete hemostasis. Sulfanilamide crystals should be dusted into the wound before the temporary dressing is applied. It is very important to bring sufficient force with the bandage against the gauze dressing to maintain hemostasis. Unless there are extensive wounds elsewhere, pain is usually not an important factor; therefore, morphine if used at all should be given in small doses ($\frac{1}{8}$ to $\frac{1}{6}$ gr.). If a state of shock exists treatment with blood plasma or whole blood takes precedence over all other considerations.

On admission to the hospital roentgenograms of the skull should be made. In most instances, stereoscopic films will be impracticable; therefore, a lateral film on the side of the wound of entrance and an anteroposterior film will suffice to localize the metallic and bony fragments. Unless the patient has been previously immunized, tetanus and gas antitoxin should be given as soon as possible after the wound is inflicted.

These operations, like most other brain operations, may be done in most instances under local anesthesia. The technic of procaine block anesthesia is described fully under the treatment of scalp wounds. It is important again to emphasize that the local anesthetic should be injected before subjecting the patient to the pain of cleansing the wound.

Wound débridement should proceed from without inward. First, all clots, dirt, and other forms of matter are washed out of the scalp wound with green soap and water followed by saline irrigation. The wound of

entrance in the skull is enlarged with rongeurs until there is adequate exposure to handle the wound in the brain itself. This point will usually be determined when a fairly normal-appearing dura mater is encountered. Usually, there has been a jagged opening made in the dura and if this opening is sufficiently large to permit débridement of the brain wound itself no further incision is needed. However, if the penetrating wound of the dura is a small one then

satisfactorily without suction, and a metal suction tip is preferable because the coagulating current may be applied directly to the bleeding vessel as it is pulled into the end of the suction tip. The débridement should be complete and all macerated brain tissue removed until viable-appearing cortex remains. In many instances, it is necessary to carry the dissection into the ventricle. Whether or not the ventricle is opened it is essential that hemostasis of the
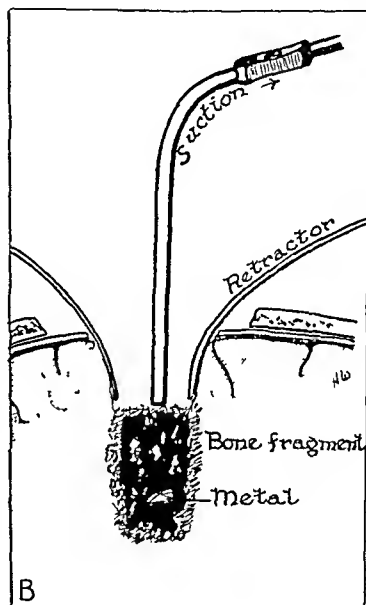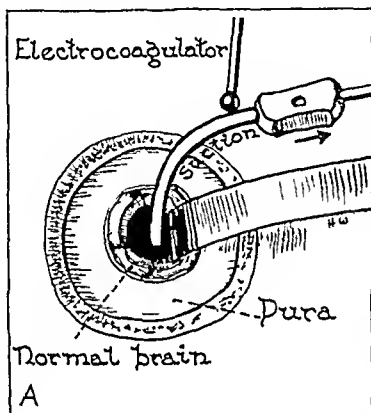
Fig. 24. Diagram of operative steps in penetrating wounds of brain. (A) By combination of suction, electrosurgery and irrigation, débridement of contused brain is started (B) Débridement is continued until all contused brain tissue and foreign bodies are removed (After Horrax.)

a dural flap should be turned downward to secure adequate exposure of the cortex.

In most instances, bleeding vessels will be encountered both in the dura and on the surface of the brain. The smaller vessels should be sealed with the electrocoagulating current and a silver clip applied to the larger ones. The brain wound will usually have been filled with clot, bits of bony fragments, and perhaps other débris. The whole area is cleaned out with suction and irrigation with Ringer's solution.

It is impossible to débride a brain wound

brain wound be absolutely complete else a large clot will form and serious consequences result (Figs. 23, 24).

There is no rule to guide one as to whether or not metallic bodies should be removed from the brain. In all instances where the missile is accessible it should be removed. However, when the metal fragment is small and has penetrated the brain to a great depth and where great damage to the brain would be necessary to remove it, then obviously it should be left alone. Small fragments may do little permanent

harm providing no infection develops about them. Sulfanilamide should be placed in the tract in small quantities.

One of the most important steps in the treatment is to secure an absolutely tight closure. That statement applies not only to the scalp but to the dura mater as well. If there is a large gaping hole in the dura it should be repaired with a fascial transplant or a piece of preserved animal membrane (Cargile's membrane). This repair should be watertight, i.e., so that the cerebrospinal fluid will not leak beneath the scalp.

The scalp should always be closed tightly. This is done in the usual manner with two layers of interrupted silk sutures

The postoperative care of these patients is similar to that of any other head case. The patient should be set almost upright in bed unless he is deeply stuporous with loss of the gag reflex. Postoperative pain is best controlled with acetylsalicylic acid, codeine, or morphine in small doses. Chemotherapy by mouth or per rectum should be maintained for a week or ten days.

Skin sutures are removed on the third postoperative day. If fluid accumulates beneath the operative wound it may be aspirated by needle.

The repair of the skull defect with a tantalum plate should be postponed for three or four weeks; certainly, until primary healing of the wound is assured.

## EXTRADURAL HEMATOMA

Of all the serious complications of head trauma, extradural hemorrhage should be the easiest to recognize and the most satisfactory to treat. Yet, in most of the large clinics the mortality from this lesion varies from 30 to 50 per cent! Three factors are responsible for these unbelievably bad statistics: First, failure in diagnosis; second, delay in operation once the lesion is sus-

pected; and third, the frequency of severe associated injuries.

The classic syndrome of extradural hematoma is as follows: The patient is dazed or rendered unconscious for a few minutes by a blow on the head. He may recover completely or may complain of headache, perhaps nausea, or a feeling of faintness; at any rate, he usually becomes rational for a while after the blow (lucid interval) Within an hour or two his mental faculties become dull and he feels sleepy. Sleep steadily progresses to coma, with stertorous breathing. The pulse becomes slow, and the blood pressure is above the normal level.

There is usually puffiness or soft induration of the scalp and temporal muscle in the vicinity of the blow to the head. The pupil on the injured side of the head is larger than normal and may be widely dilated and fixed. The contralateral arm and leg may be weak, and a positive Babinski response may be present. Fits, particularly jacksonian convulsions, may occur.

Of course, long before all of these symptoms and signs have developed, the diagnosis should be made and the patient operated upon. If the true condition is still unrecognized at this stage, the coma deepens, the pulse rate increases, the blood pressure falls, and the temperature rises. In fact, medullary function fails gradually and the patient dies within a few hours.

If the patient is hospitalized during the early stages of the lesion, additional valuable data may be obtained from roentgenograms and lumbar puncture. A linear fracture through the temporal bone which crosses the groove of the middle meningeal artery is valuable confirmatory evidence of extradural bleeding. An elevated lumbar cerebrospinal-fluid pressure is valuable evidence of an extradural hematoma, for in most cases the pressure will be well above normal, often as great as 400 mm. of water. However, lumbar puncture is contraindi-

cated if the diagnosis of extradural clot is clear without it.

An extradural hematoma usually arises from laceration of the middle meningeal artery, but any of the meningeal vessels may be torn, producing a clot over any part of the cerebral hemisphere or cerebellum. The associated linear fracture is an excellent guide to the probable location of the clot (Fig. 14).

Like any other clinical syndrome, all the classic symptoms and signs of extradural hematoma are not present in every case. For instance, the patient may never regain consciousness after the blow—an occurrence frequently seen when there is severe associated brain injury. However, the other objective signs of extradural hematoma can be found if searched for carefully. The lucid interval may be prolonged. McKenzie's case was rational for 11 days before the tell-tale symptoms and signs developed. The unilateral dilatation of the pupil may be absent, particularly if the bleeding comes from the anterior or posterior meningeal vessels. These variations do occur, but the classic syndrome of extradural hemorrhage is more constant and the pattern and sequence of symptoms more exact than in most other clinical entities.

A lowered mortality from extradural hemorrhage must come from early diagnosis with early surgical interference.

Early diagnosis cannot be expected until every physician—even those who care for head-trauma patients only occasionally—knows the early symptoms and signs. It is impracticable to hospitalize every patient who has been unconscious for a short time. However, the attending physician can sit down with a responsible member of the family and painstakingly explain the early danger signs of intracranial complications. *No patient who has been unconscious from a head blow should be allowed to sleep longer than two hours during the first night without being aroused.* This is often the only way to distinguish between normal and pathologic sleep. It is better, of course, for the patient to be hospitalized, but one must be very careful that the nursing staff know the danger signs and that they observe the patient carefully every hour. Unless the nursing service is "air-tight" it is better to leave a responsible relative by the patient's bedside during the first night.

The next improvement must come with early treatment. This is the one lesion in which the sleepy attending surgeon cannot tell his house surgeon to "watch the patient carefully and I will see him the first thing in the morning." When the clinical signs and symptoms are present, operate without delay. When the signs are suggestive but not positive, operate without delay, unless the general condition of the patient makes an exploratory operation hazardous.

**Surgical Technic.** When an extradural hemorrhage is suspected, an exploratory burr hole should be made in the midportion of the temporal bone just below the insertion of the temporal muscle. The skin incision should be outlined so that the initial incision can be converted into a subtemporal decompression (Figs. 25, 26, 27).

If a hematoma is verified, the subtemporal decompression should be completed in order that sufficient exposure may be secured to deal with the clot and the bleeding vessels. The trephine opening should be placed at the upper edge of the squamous bone; the bone above the zygoma may be exceedingly thin. When the burr has removed the inner table, black coagulated blood will present into the opening. However, if the clot is low in the temporal fossa it may have dissected the dura from the floor of the skull and normal-appearing dura mater may be encountered when the opening is made in the upper part of the wound.

After carefully separating the dura from the inner table the squamous portion of

the temporal bone is removed with flat rongeurs. Clots are removed with suction and irrigation with Ringer's solution The removal should start low in the temporal fossa in order that the meningeal artery may be identified and ligated as soon as possible Once the middle meningeal artery

with several layers of interrupted silk sutures.

If an extradural hematoma is suspected and the linear fracture in the skull and the boggy scalp above it are in any other than the temporal fossa, then the exploratory burr holes should be placed over the frac-
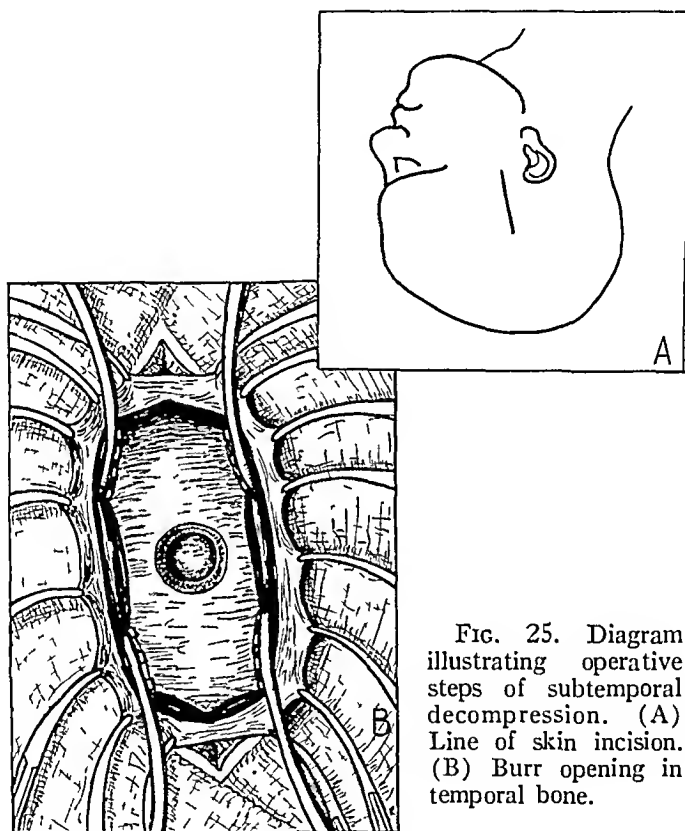


Fig. 25. Diagram illustrating operative steps of subtemporal decompression. (A) Line of skin incision. (B) Burr opening in temporal bone.

has been secured, the clot may be removed leisurely with irrigation and suction

In the meantime, if shock is impending, blood plasma or blood should be started When removal of the extradural clot is complete, a small opening should be made in the dura if discoloration and tension indicate a probable subdural hemorrhage or hygroma. When subdural blood or fluid has been evacuated the incision in the dura is closed with black silk.

Closure of the wound is accomplished

ture line. An extradural hemorrhage is seldom encountered without a linear fracture of the skull immediately above it, therefore, when in doubt, explore first in the area of fracture. This statement applies equally when the fracture line involves the posterior cranial fossa. The more usual clots in the middle fossa usually produce the characteristic symptoms and signs, whereas a clot over the frontal lobe or over the cerebellum produces very atypical symptoms.
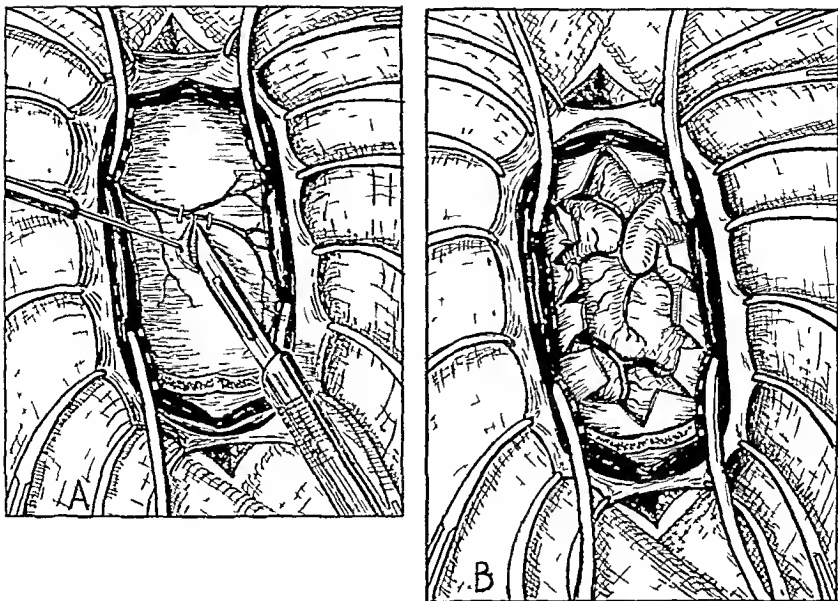
FIG. 26 Diagram of operative steps in subtemporal decompression (A) Incision of dura mater between silver clips applied to middle meningeal artery. (B) Crucial incision of dura mater exposing cortex of temporal lobe.
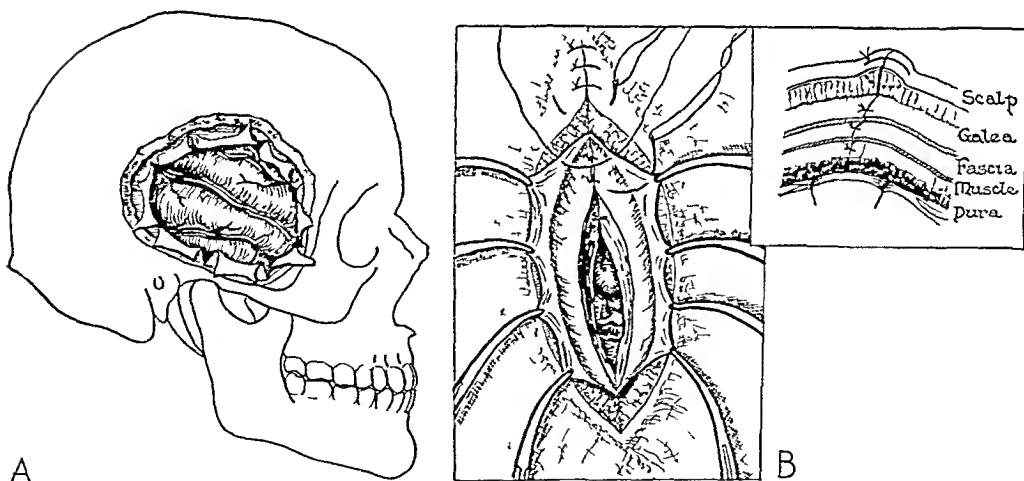


FIG 27 Diagram of operative steps of subtemporal decompression (A) Size and position of opening in temporal bone. (B) Technic of closure of wound in layers with interrupted sutures of black silk.

an acute subdural hematoma or an extra-dural clot.

Treatment of this lesion is often unsatisfactory. Arterial hemorrhage may be difficult to control because there are few clinical findings to guide one accurately to the site of the bleeding vessel. Other things being equal, the exploratory craniotomy should be planned at the point of greatest brain trauma if this information is available from clinical data.

Procaine anesthesia is used unless the patient is exceedingly restless and then intravenous pentothal is an ideal compromise. The dura is usually tight, and when it is incised a thin stream of blood—either bright red or dark blood—will spurt from the opening. After evacuating the blood by suction the subdural space is irrigated with warm Ringer's solution. The brain will gradually expand until the space is obliterated, providing all of the blood has been removed. Failure of the brain to expand is due to one of two factors: (1) There has been irreparable damage to the cerebral blood supply or (2) the subdural blood has not been completely evacuated.

When there is doubt about complete evacuation additional burr holes should be placed at strategic points and through-and-through irrigation with Ringer's solution made with a soft rubber catheter. If evacuation has been complete and the surface of the brain comes up flush with the dura, drainage of the space is unnecessary. If, however, there is continued oozing and the subdural space is not obliterated, then a soft rubber tissue drain may be placed beneath the dura for 24 hours.

Since most acute hematomas occur in patients who have also sustained serious brain injury, dramatic improvement after surgery is not to be expected. The usual nonoperative treatment measures should be followed closely in the further treatment of the patient. However, if the evacuation of clot has been complete, the

clinical signs of increased intracranial pressure should have subsided. If the intracranial pressure again rises, re-exploration of the wound often reveals that the lesion has reformed.

Subdural Hygroma. This interesting lesion consists of a subdural collection of clear, yellow, or blood-tinged cerebrospinal fluid.

The lesion is presumably caused by a small tear in the arachnoid which allows cerebrospinal fluid to escape into the subdural space. The small opening in the flimsy arachnoid acts as a "ball-valve," permitting cerebrospinal fluid to escape into the subdural space but not permitting its return to the subarachnoid space. Restlessness, coughing, sneezing, or a convulsion will force fluid in relatively large quantities into the subdural space from a very small tear in the arachnoid.

The clinical symptoms are similar in every respect to subdural hematoma. The lesion occurs with all grades of head trauma, therefore the clinical symptoms associated with the lesion vary from patient to patient. It should always be suspected when an otherwise smooth convalescence is interrupted by signs of increasing intracranial pressure. Headache is usually persistent and troublesome; day by day the head pains intensify. Mental confusion, usually of mild degree, is common. Also, dizziness, nausea, vomiting, and drowsiness are frequently observed. The pulse rate slows; the spinal-fluid pressure increases; the optic disks may become swollen, and the retinal veins become engorged. Clinical signs of localized brain damage are seldom seen.

The diagnosis can be established positively only by cranial exploration. A burr hole placed at the insertion of the temporal muscle in the midparietal area will usually identify the lesion. The dura is usually not tense, but when it is incised fluid may spurt in a stream from the small opening. As the

fluid is evacuated, the brain may be found to be pushed away from the dura sometimes as much as an inch or an inch and a half. Once the evacuation of the fluid is accomplished the brain begins to fill this space, and without further manipulation on the part of the operator the fluid will be completely expelled by the expansion of

stances secondary evacuation is required.

Chronic Subdural Hematoma. It is believed that this lesion is always the result of head trauma. The injury is usually considered trivial by the patient. It is rarely severe enough to cause a fracture of the skull.

In some cases, symptoms appear within
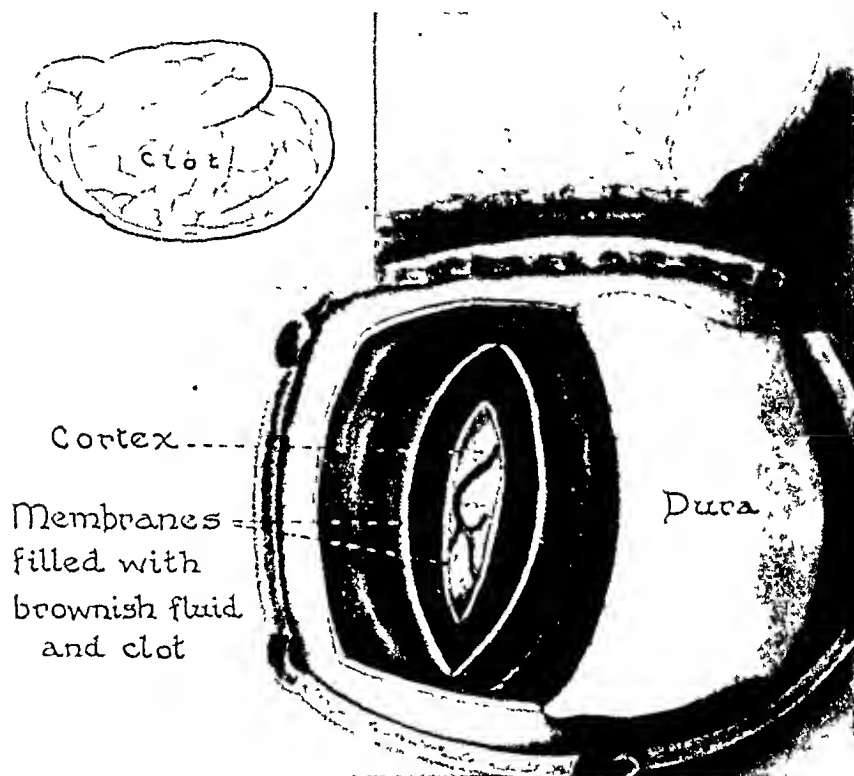


FIG. 28. Diagram illustrating important anatomic features of a subdural hematoma. Note thick outer membrane and thin inner membrane. Insert illustrates average lateral extension of hematoma over surface of cerebral hemisphere.

the brain, particularly if the head of the operating table is lowered. Subdural hygromas, like true subdural hematomas, are frequently bilateral, therefore both hemispheres should always be explored.

The prognosis for complete recovery is excellent providing the concomitant damage is not severe. Occasionally, subdural hygromas reform, and in such circum-

a few days after a minor head trauma. In others, weeks or months may elapse before any recognizable symptoms develop. The difference in time of onset of symptoms is probably dependent upon the quantity of blood escaping originally into the subdural space. In any event, whether the amount is small or large it soon becomes encapsulated in a sac of mesenthelial cells. As this

change occurs, the rising osmotic pressure within the sac attracts fluid from the blood stream and gradual enlargement of the hematoma ensues (Figs. 28, 29). As the brain becomes progressively compressed, symptoms increase in severity until death supervenes unless the hematoma is evacuated.

HEADACHE is perhaps the most constant and persistent symptom of subdural hematoma. It may be unilateral but more often is generalized, and it is usually described as persistent and throbbing. In many patients, headache, present from the time of the original trauma, becomes intolerable only in the later stages of the lesion.

DROWSINESS and changes in mental alertness are the next most common symptoms. The patient's family may notice that he is gradually "slowing down." He forgets things easily and he himself may complain of faulty memory. This dulling of the psychic activity progresses until stupor or coma supervenes. Hematomas over the left hemisphere (in the right-handed) are more often associated with "blunting" of mental functions.

NAUSEA AND VOMITING are almost always present as a late symptom. As headache becomes more intolerable, the other signs and symptoms of increased intracranial pressure appear.

DIZZINESS, to the point of being unsteady when walking, is a frequent symptom. When the position of the head is changed, the patient may feel that he is pitching forward.

FAILING VISION and not infrequently DIPLOPIA are often part of the symptomatology.

CONVULSIVE SEIZURES seldom occur and localized paralysis or hemiplegia is but rarely encountered.

The neurologic signs are usually those of increased intracranial pressure. The pulse is slow—on an average of about 60 beats per minute. The blood pressure may be normal or moderately elevated. Ophthalmoscopic examination usually shows engorgement of the veins with blurring of the disk margins; frank papilledema may be present in the later stages.

Diagnostic lumbar puncture yields invaluable evidence in most cases. The pressure is usually but moderately elevated, the average being about 250 mm. of water. The spinal fluid is frequently xanthochromic; careful examination may be necessary to demonstrate a slightly yellow tint. The total protein is usually moderately increased and the cell count is normal.

X-ray studies of the head yield no valuable information, and air studies on patients with suspected subdural hematoma are, except in unusual circumstances, an unnecessary refinement in diagnosis.

In all cases of suspected chronic subdural hematoma the easiest, most satisfactory method of establishing the diagnosis is by exploratory trephine openings in the skull. Such an exploration can usually be done under procaine infiltration anesthesia and should not be attended with surgical risk.

The burr hole is placed at the insertion of the temporal muscle about 2 cm. anterior to the lower end of the motor cortex. The appearance of the dura usually establishes the diagnosis; it is thickened and discolored, usually of a blue-green hue. A small opening in the dura will identify the outer membrane of the clot. Before opening the sac, the opening in the skull should be enlarged downward beneath the temporal muscle until it is approximately the size of a silver dollar. The dural opening is enlarged crucially and the membrane ruptured. If there are no clots the sac may completely evacuate itself spontaneously. If a solid clot remains in the sac then trephine openings should be placed in the midportion of the frontal bone and the midparietal area, and the contents removed

by irrigation with Ringer's solution between the three trephine openings. In any event, the surgical effort is directed toward the evacuation of the clot and no attempt to remove the membrane should be made. It has been proved by experience that this treatment is all that is required for the relief of most cases of chronic subdural hematoma. Occasionally, complete evacuation of the clot is impossible by multiple trephine openings, and, in such circum-

the sac and drainage to the exterior is permitted for from 36 to 48 hours. External drainage is always a potential source of infection, therefore the usual prophylactic administration of one of the sulfonamides is indicated. Subdural hematomas are bilateral in approximately 20 per cent of cases. Therefore, both subdural spaces should be explored in every case.

The postoperative care of chronic subdural hematomas is often a trying problem.



Thick outer
membrane

Dura

Thin inner
membrane

Arachnoid
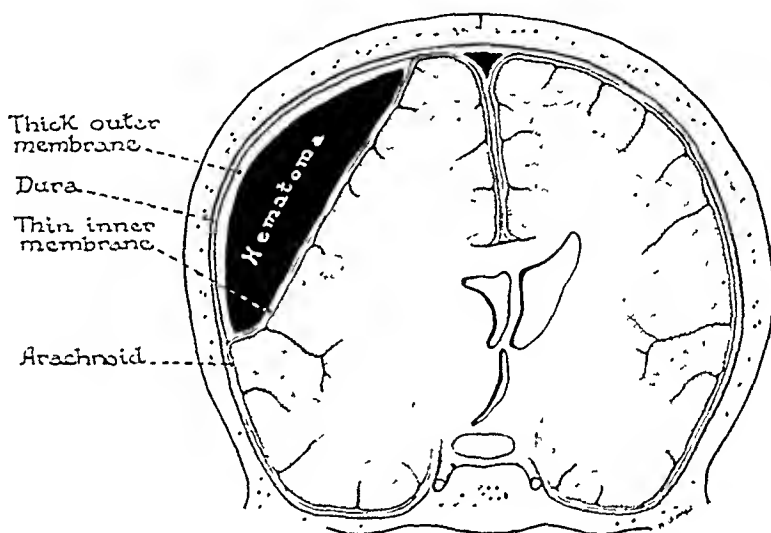
Hematoma

Fig. 29. Diagram illustrating position of a subdural hematoma with respect to dura mater and cerebral cortex. Note shifting of ventricular system to opposite side.

stances, reflection of a bone flap with complete excision of the sac is necessary (Fig. 28).

As the contents of the sac are evacuated the brain gradually expands to obliterate the space. If the brain fails to expand it may be due to permanent damage to the cerebral vessels by the pressure. Expansion of the brain is facilitated by lowering the head of the operating table and by rapid administration of isotonic fluids intravenously.

A small rubber tissue drain is placed in

If the patient has been in a stupor before operation he will probably remain so for a week or more. Not infrequently the patient will regain consciousness immediately after evacuation only to become drowsy again a few days later. In such circumstances, the wounds should be re-explored and further evacuation of the sac attempted. These secondary operations are most frequently negative explorations. Most patients again awaken in a day or so and the cause for the recurrence of symptoms and their subsequent disappearance remains unexplained.

## SUBDURAL HEMATOMA
## IN INFANTS

It is difficult and at times impossible to distinguish clinically between chronic subdural hematomas in infants and congenital hydrocephalus. So difficult is the clinical diagnosis that it may be dogmatically stated that every infant whose head enlarges more rapidly than normal should be considered to have a subdural hematoma until proved otherwise. These lesions in infancy, like similar lesions in adults, respond dramatically to treatment when an early diagnosis is established.

Trauma at birth is the most important etiologic factor. Malnutrition, particularly when associated with scurvy, is a common contributory cause.

The surgical pathology of chronic subdural hematoma is the same in infancy as in adult life; the acute fulminating form is seldom seen in infancy.

The first symptom of infantile subdural hematoma is difficulty with feeding; regurgitation and vomiting are common. Gradual abnormal enlargement of the head occurs, usually first noted after the third month of life. The fontanels increase in width and the shape of the head resembles hydrocephalus.

A positive diagnosis is made by fontanel puncture. A 20-gauge needle with a short bevel is pushed carefully through the scalp at the lateral margin of the anterior fontanel. It is difficult to describe the sensation produced as a needle penetrates the dura mater; a distinct "click" is felt as the point enters the subdural space. If there is a hematoma present, yellow, straw-colored, or bloody fluid escapes through the needle, provided the hematoma is liquefied. Solid clots, certainly hematomas with a very thick, tough, outer membrane, are often encountered in infants; therefore, prompt evacuation of characteristically appearing fluid does not always occur. In such circumstances, the needle should be inserted gently to a depth of 3 cm. in the direction of the lateral ventricle and unless clear ventricular fluid is encountered one should suspect a solid clot. If the cause were one of simple hydrocephalus, the enlarged ventricle would have been encountered at this depth. Bilateral fontanel punctures should always be made, as the incidence of bilateral hematoma is high.

Repeated needle aspirations are sufficient to cure some of the liquefied hematomas encountered in infancy. In the author's series there have been three instances of permanent cure with aspiration alone. However, in many infants repeated aspirations will not effect a cure even when the contents of the sac appear to have liquefied. It is believed that the tough inner membrane prevents the soft infant brain from expanding; certainly, in many cases, until this membrane either is removed completely or broken in many places the patient will not recover.

A small frontoparietal osteoplastic flap is turned down under local anesthesia. A sugar nipple saturated with whiskey makes an ideal adjunct to local anesthesia in infants. Usually the skull is so thin that the flap can be cut with scissors. Careful hemostasis is especially important in infants because small amounts of bleeding may cause hemorrhagic shock. A dural flap is reflected over the hematoma and in many instances the whole sac can be "teased" away from its bed without undue hemorrhage. After the lesion is removed the brain should be made to expand before closing the wound. This can usually be accomplished by lowering the head of the table and giving rapidly isotonic fluids intravenously. When the lesion is bilateral, a week or ten days should elapse between the first and second operations.

# 4

# Cranioplasty

## Barnes Woodhall, M.D.

Cranioplasty, the plastic repair of defects of the skull, is an operative procedure that has been influenced by the exercise of much surgical ingenuity and the use of many substitute materials. Times of warfare, marked by a concomitant increase in the number and variety of skull defects, have acted as periodic stimulants toward the perfection of surgical technics, and such technics are readily applicable to skull defects incidental to the injuries of civilian life. The first cranioplasty was performed in 1670, but many years were to elapse before the work of Ollier in 1859 in bone grafting gave the experimental information necessary for the subsequent successful clinical repair of skull defects. Until World War I, the use of animal bone, celluloid, aluminum, gold, silver, platinum, autogenous and heterogenous bone, cartilage, and decalcified bone had been recorded. With the exception of autogenous bone, and perhaps celluloid, these materials were tried and virtually discarded.

The repair of cranial defects was the most frequent surgical procedure in the rehabilitation of head wounds during World War I. With the exception of autogenous bone and celluloid plates, all other cranioplastic materials were abandoned by military neurosurgeons of that period. Autogenous transplants from the skull, tibia, scapula, and ribs became the material of choice in most hospitals with celluloid plates reserved for the repair of extensive defects. A second World War has again stimulated interest in cranioplasty. The occurrence of great numbers of casualties exhibiting skull defects frequently of large size and deforming character was associated most opportunely with the development of certain alloplastic materials already tested in the laboratory and, to a lesser degree, in the clinic. It is of these substances and their application to cranioplasty that we are chiefly concerned at this writing.

## INDICATIONS FOR CRANIOPLASTY

Considerable difference of opinion has existed concerning the varied benefits to be derived from cranioplasty. Symptoms attributed to a loss of a portion of the skull have been regarded by some observers as arising from associated damage to brain tissue. Studies of a large number of patients with cranial defects in World War I led to the general belief that any defect, and in particular the larger ones, may be accompanied by symptoms referable to the defect itself, and that the disability of a patient with serious cerebral damage associated with loss of a portion of the skull might be alleviated by cranioplasty. The validity of these impressions has been established by experience in World War II. The indications for cranioplasty may be summarized as follows:

1. The existence of headache and other

symptoms of the "syndrome of the tre-
phined," including vertigo, local tenderness,
fear of injury, and a subjective feeling of
insecurity, easy fatigability, mental depres-
sion, and intolerance to vibration. Tender-
ness over the scalp scar and particularly
over the brim of the defect is a common
complaint. Symptoms are exaggerated by
exertion and sudden postural changes.

2. Undue pulsation of the underlying
brain. The palpable, rhythmic movement
of the brain, and the gross protrusion or
regression of the cerebral hernia, are
sources of disquietude. The attendant, sub-
jective sensation of throbbing may disturb
normal sleep.

3. Exposure to trauma of the underlying
brain. This represents one of the most
valid indications for cranioplasty. Second-
ary injury, through blunt or sharp force
transmitted through the defect, may be
formidable.

4. Cases with deforming and repulsive
defects, particularly of the frontal and
supra-orbital regions of the skull. Cranio-
plasty, in one form or another, is manda-
tory for such patients.

5. The assumed relief of a convulsive
state.

To these more or less cogent reasons
may be added certain military regulations
governing the treatment and disposition of
patients with skull defects when they are
encountered under service conditions. In
summary, it is imperative to repair all
skull defects over 3 cm. in diameter if a
return to active-duty status is desired. In
personnel who will not return to duty be-
cause of a coexisting cerebral injury, cra-
nioplasty is still indicated in the hope of
reducing in every possible fashion the effect
of the initial injury. With the development
of the simple technic of cranioplasty to be
described, there seems little reason to alter
these indications for cranioplasty in cranial
defects arising from civilian injuries.

## CONTRAINDICATIONS TO CRANIOPLASTY

From the point of view of the number
of cases, the repair of skull defects caused
by war wounds of the head represents one
of the most important technical procedures
in rehabilitation military neurosurgery. A
widespread appreciation of the sequelae of
war wounds will be of vital import for
many postwar years. Furthermore, the ap-
plication of cranioplasty to civilian injuries
of the skull—be they traumatic, infectious,
or neoplastic in origin—may be illustrated
most clearly by a discussion of the prob-
lems encountered in the more numerous
cases of warfare.

The care of acute injuries to the head
resulting from war wounds is divided
among several echelons of medical support.
In most cases the wounded soldier passes
through the battalion aid station and clear-
ing station of the division and then back to
an evacuation hospital. The preservation
of life and the prevention of infection by
débridement and primary closure are the
functions of the evacuation hospital or the
special surgical unit in the care of acute
head injuries. After an appropriate interval
of rest such patients are transferred to the
base or numbered overseas general hos-
pital. The treatment of infection and the
guidance of the later stages of convales-
cense from the head injury are the respon-
sibility of these installations.

The mortality among those that survive
the initial battlefield wound and are
treated in the installations noted above
varies between 14 per cent in one group of
1400 cases observed in the American forces
to figures as high as 22 per cent reported
in other theaters of operations. Although
accurate figures are difficult to obtain it
appears apparent from a study of separate
but small series of cases that approxi-
mately 60 to 70 per cent of the patients
sustaining and surviving open head wounds

must be considered unfit for duty and are returned to the zone of the interior for further study and rehabilitation.

A complication important in determining the extent of the eventual neurologic defect and influencing reparative surgery to some degree is the presence or not of infection. In two British series of cases fatal infection supervened in 3.7 per cent and 10.8 per cent, respectively, of patients operated upon. In another series of 494 patients who had either primary or secondary operations in base hospitals, 33.5 per cent showed some evidence of infection during the period of observation. 12.0 per cent developed superficial scalp infections, 5.5 per cent developed subgaleal infection, 7.5 per cent developed brain abscess, 8.5 per cent were complicated by meningitis, and 17 per cent had retained bone fragments. In spite of the high incidence of meningitis and brain abscess, the resulting mortality of 4.3 per cent was gratifying and suggests the beneficial influence of applied chemotherapy. The total of serious infections therefore amounted to about 15 per cent, a figure which has remained rather static in all theaters of operation.

## REHABILITATION PROBLEMS IN ZONE OF INTERIOR

When the patient with a healed head injury returns to the zone of the interior he presents at least two important problems to the rehabilitation neurosurgeon. The first comprises an evaluation of the extent and degree of residual brain damage, an evaluation which may be carried out by neurologic and psychiatric surveys, supplemented by electro-encephalography and pneumo-encephalography. It is obvious that such an evaluation is a pertinent factor in determining disposition to some type of duty or to some other status such as discharge to civilian life. The second and main problem is that of repairing skull defects in otherwise fit individuals for return

to duty or in patients whose skull defects represent merely a part of a disabling cerebral injury. The reparative surgery incidental to this second problem may be complicated by several sequelae of the original injury such as extensive scalp scars, residual brain abscess, orbital cerebral fungus, retained bone fragments, or associated injuries to special or adjacent structures of the skull.

## NEUROLOGIC DEFECTS

The time interval between initial injury and observation in the zone of the interior averages between three and four months. By this time the more widespread neurologic defect characteristic of the immediate posttraumatic course of the injury has resolved to a large extent and the residual neurologic defect observed three months after injury may be considered more or less permanent. At this time hemiplegia, associated with aphasia if the dominant hemisphere is involved, is by far the most common neurologic defect. Loss of vision, either due to direct, complete, or partial involvement of the visual areas or more commonly due to destruction of the optic nerve or orbital contents, ranks next in numerical importance but first from the point of view of residual disability. Variability in the extent and degree in character of the residual neurologic defect is as extensive as the vagaries of the inciting force.

## POSTTRAUMATIC CONVULSIVE STATE

A review of previous reports indicates the fact that when the criteria for dural-cortical penetration in war wounds of the brain are defined clearly, the incidence of posttraumatic epilepsy varies between 35 and 50 per cent. It is also apparent that the most probable period of onset of seizures lies within the first year between the fourth and twelfth month following injury. The

remaining 50 per cent may become evident within the following five years or later. In spite of adequate early débridement and more improved methods of combating infection, the incidence of posttraumatic epilepsy appears quite similar in the present series of war wounds and has remained during the early period of observation at a level of 40 per cent. The development during the years intervening between World War I and World War II of the electro-encephalogram and of more definitive methods of therapy may allow a clearer understanding of the development of the posttraumatic convulsive state and its treatment.

The nonspecific response of the brain to injury noted in the electro-encephalogram is the recurrence of slow waves varying in frequency from $\frac{1}{2}$ to 6 per second, the so-called delta activity. This slow cortical electrical activity is most marked during the acute posttraumatic period. If it disappears progressively during the first three posttraumatic months, it may be correlated closely with evidence of clinical improvement. Regression of delta activity, therefore, may act as objective evidence of the rate and degree of improvement. If progressive changes in cortical electrical activity in a series of severe head injuries are observed, it will be noted that such changes fall into two well-defined groups. In the first group, the delta activity customarily noted during the acute posttraumatic stage will gradually disappear to be replaced by normal electrocortical activity. This resolution may occur three to four months following the initial injury although infrequent delta activity may be found at a later period. The second group will exhibit the development of epileptogenic focal activity, first manifesting itself when delta activity has largely disappeared. In order of their frequency, such epileptogenic encephalographic foci are as follows: (1) 6 to 8 and 14 to 22 per second activity; (2)

high voltage 25 to 30 per second activity; (3) isolated spike activity either negative, positive, biphasic, or triphasic; (4) slow wave and slow spike activity; (5) high voltage 6 per second activity; and (6) 3 per second spike and dome activity, the petit mal variation.

It is apparent, therefore, that the onset of the convulsive state following a war wound of the brain may be predicted by observing the gradual alteration from the customary acute posttraumatic delta activity to one or more characteristic types of epileptogenic encephalographic foci. The appearance of such abnormal changes in the electro-encephalogram dictates the immediate institution of anticonvulsive conservative therapy.

## RESIDUAL INFECTION

It is inevitable with the incidence of primary infection as noted above that certain residual infections will become apparent after transfer of the military patient to the zone of the interior. Such infections are associated with retained bone fragments or foreign bodies, commonly suture material. Since the majority of these patients have skull defects, the former infection manifests itself by protrusion or herniation of the brain, by an increasing neurologic defect, and by dulling of consciousness. In such cases it is common to obtain a history of a pre-existing infection. The number of such cases is small. Infection from retained suture material, dural grafts, or small areas of infection in bone manifests itself by acute or chronic scalp infection which demands drainage and removal of the focus of infection before further reparative surgery can proceed.

A special form of infection may be associated with cerebral fungus formation in the orbit as a sequel to combined orbital and frontal-lobe penetrating wounds. Such infections manifest themselves by a chronic or periodically acute orbital cellulitis in the

The assumption that this pericranial bridge enhances circulation in the graft is probably not valid. In most cases, however, the graft is obtained from a closely adjacent area of skull (Fig. 30).

Transplants from the outer table of the skull are not immediately stable. A firm, evenly distributed pressure dressing must be applied and if the defect is of appreciable size the individual patient should be confined to bed in a horizontal position for at least seven days.

The curved surfaces of the scapula and ilium appear well disposed toward the plas-

lar cranial defects caused by removal of bone·en bloc or to defects that may be altered into such a design. The ninth and tenth ribs are exposed in the posterior axillary line, the periosteum is incised and elevated, and pieces of rib slightly longer than desired are resected. The ribs are split with a broad, thin chisel, forming two sections roughly approximately the normal contour of the skull. In this technic, after exposure of the defect, a ledge is cut in the two opposing sides of its longer axis, into which the ribs may rest and be secured. The rib sections, regardless of num-
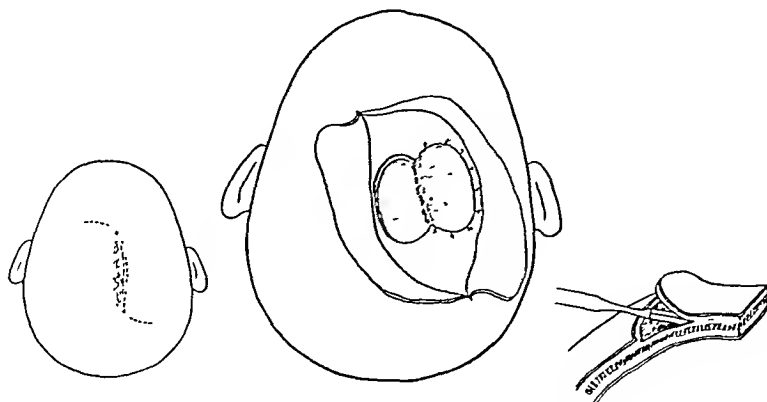


FIG. 30. Drawing of usual autogenous graft from outer table of skull, explained in detail in text.

tic repair of skull defects. The major operative procedures required for the exposure and preparation of such grafts make further discussion of these methods at this time of purely historical interest. In the same category may be placed the method of osteoperiosteal ·grafts obtained from the tibia, which in the past have been considered ideal for the repair of small, linear defects.

Split-rib Graft with or without Periosteum. When the defect is larger than may be repaired suitably by a graft secured from the outer table of the skull, a split-rib graft is a satisfactory procedure. This method is peculiarly adaptable to rectangu-

ber and whether a cut or smooth surface is uppermost, are adjusted to fit accurately against one another and into the prepared ledges. After the preliminary coaptation, drill holes are placed in the ledges and in the rib ends and firm fixation secured by the use of silver, stainless steel, or tantalum wires. Galeal and scalp closure are carried out without drainage. As is true in all cranioplasties using autogenous transplants, the region of the repair must be protected during the subsequent period of stabilization.

Autogenous Cartilage Grafts. Although cartilage grafts remain as such and cannot be considered as strong as bone grafts for

the repair of cranial defects, they may be used to advantage in the repair of small, deforming defects of the supra-orbital ridges and the region of the glabella. It is possible in most cases of this character to expose the defect by plastic excision of the overlying scar, and, indeed, in these instances the revision of the frontal scar forms an important phase of the procedure. The thickened pericranial-muscle scar about the edges of the defect is preserved, and not displaced or retracted. Upon occasion, an incision may be made along the superior margin of the defect and a taut tent of tissue elevated above this region into which the proposed graft may be inserted. The bony margins of the defect rarely need further contouring other than that required for smoothing and perhaps moderate beveling of its superior border. The lower extent of such a defect may be nonexistent in terms of a true ledge.

The rectangular transplant, secured from rib cartilage, is contoured by cutting and inserted flush with the residual skull margin. Its anterior, free border is adjusted to conform to the desired curve of the region involved. Fixation of the transplant is secured by overlocking sutures or by the pressure of overlying soft tissues. Postoperative dressings must be firmly stabilized. Essentially the same technic may be used in the repair of small cranial defects over the convexity of the skull.

Cast Blood-bone Chips Autogenous Graft. This ingenious but technically difficult use of autogenous bone in the repair of cranial defects is mentioned chiefly because it represents another application of the clotting mechanism of the blood to diverse fields of surgery. The details of the preparation of the casts and molds and the formation of the blood-bone graft should be read in the original presentation of this work. In brief, a metal replica of the proposed graft is formed by routine methods and from this a metal die and counterdie

are poured. After exposure and beveling of the edges of the cranial defect, cube fragments of bone, 0.25 to 1.0 cm. in size, are removed from the inner table of the ilium. Blood is withdrawn from the iliac wound and mixed with the bone chips in the mold. The upper part of the mold is superimposed and the entire mold inserted in a sterilized hand press. Pressure is applied and maintained until the blood has clotted, the fibrin of the clot acting as a cement in holding together the bone chips under pressure. No local fixation of the graft is required other than the pressure of the scalp flap and suitable dressings.

## CELLULOID

With the advent of certain other alloplastic materials, cranioplasty with celluloid has assumed the status of an outmoded and historically interesting procedure. Details concerning its application will be omitted except for the statement that, until recent times, celluloid was the material of choice for the repair of extensive defects involving less complicated contours of the skull.

## VITALLIUM

This alloy of cobalt, chromium, and molybdenum possesses two of the essential requirements of any cranioplastic substance: its tensile strength is tremendous and it is quite inert in tissue. Vitallium, however, is not malleable and must be cast from impressions obtained directly from the actual margin of the defect to be repaired, although less accurate plates may be cast from percutaneous impressions. It may also be procured in stock lengths, widths, and gentle contours, the forms somewhat suggesting those of split-rib grafts. To the length and other dimensions of the vitallium plate or form, the area of the skull defect may be adjusted. Forms 6, 10, and 14 cm. in length, 2 and 3 cm. in width, and 1 or less mm. in thickness can

be altered by contour pliers, and the use of the requisite number of such stock lengths, closely approximated, will suffice to close the majority of cranial defects over the convexity of the skull. Although some contour change is possible in the cast vitallium plates through the addition of annealed slots, this substance is not applicable to the repair of multicontoured defects of the frontal and supra-orbital regions of the skull. Fixation is secured with either form of this alloy with inset, vitallium screws.

### TICONIUM

Ticonium "wrought" is an alloy of nickel, cobalt, chromium, and molybdenum. It is strong, light, malleable, and inert in tissue, and appears to be an ideal material for cranioplasty. Comprehensive experimental studies have indicated its potential value in the repair of cranial defects but at this time no clinical reports of its application are available.

### TANTALUM

A technically facile form of cranioplasty has been found in the use of the element tantalum, which possesses not only a strength comparable to that of steel but two other essential requirements of any cranioplastic material: (1) Tantalum to all practical purposes may be considered absolutely inert in tissue; (2) tantalum is malleable, and this inherent malleability allows molding, contouring, adjustment by cutting, or any other means either before operation or at the time of the operative procedure.

Several technics have been evolved for the preparation and insertion of tantalum plates. The most refined technic and the only one applicable to the formation of multicontoured plates such as are necessary in the repair of extensive frontal defects involves pre-forming of the tantalum plate. Insertion and fixation of the plate may be accomplished by a choice of methods.

Briefly stated, the method of pre-forming a tantalum plate is as follows. After removal of the long hair the margins of the skull defect are palpated through the scalp and marked with an indelible pencil. Softened dental compound is molded into the defect and for a considerable distance upon the surrounding scalp contour. A model of the defect is then formed by pouring dental stone or plaster into the mass of hardened dental compound and upon this cast the mark of the indelible pencil will persist. The depressed area within the cast, representing the depth and extent of the bony defect, is filled with wax and contoured to fit the surrounding scalp outline. In complicated frontal defects this temporary wax prosthesis may be placed in the actual skull defects, in a supra-orbital defect for instance, and compared roughly with the opposite side. In uncomplicated defects of the vault of the skull the convexity of the wax fill should be overemphasized to compensate for the customary thinning and scarring of the overlying scalp and for the subsequent slight inlay of the plate.

A mold is next made with any of the molding sands, including the wax restoration and an ample mass of the adjacent skull contour. A die is poured with zinc, or, in the case of larger defects, with hydromite. The surface of the die after cooling is painted with a solution of alcohol and talc. A soft clay, such as moldine, is adapted about the circumference of the zinc die to act as a mold for a counterdie of poured lead. The required size of 0.015 inch tantalum plate is roughly fashioned with at least 1 cm. greater diameter than assumed necessary to provide for the varying convexity of the plate and for possible enlargement of the bony defect at the time of operation. The plate is then swedged between die and counterdie with a hand or hydraulic press. A single hole is bored in

the proposed dependent portion of the plate or in its central portion for drainage purposes and the plate is then reswedged. Before use the plate is cleansed in laboratory cleansing fluid, washed in running water, and sterilized in an autoclave. The material and apparatus required for the formation of such plates are available in any dental laboratory and the technic for their formation is not an exacting one.

Other less refined methods may be used for forming tantalum plates, particularly those with simple contours. These include (1) the pre-forming of plates about a basic model of the skull, with the only individual variation being the size of the plate, (2) the hammering of plates with the aid of pre-formed plaster molds, and (3) the simple preparation of plates at the operating table by hammering or contouring with contour pliers.

The majority of tantalum cranioplasties may be done under local anesthesia and the required preparation of the bone is well tolerated with the aid of preoperation sedation, consisting of nembutal gr. 1½ ninety minutes before operation and morphine gr. ¼ and atropine gr. $\frac{1}{150}$ thirty minutes later.

In unilateral and bilateral frontal defects the use of a coronal scalp flap and manipulation about the frontal sinus and orbit demand general anesthesia, preferably with intratracheal ether. Insertion of the plate is facilitated by placing the area of the skull defect on a horizontal level and full use of the cerebellar frame and other adjuncts to such posturing is advocated. The majority of scalp scars resulting from the primary débridement overseas or in civilian injuries are linear scars of varying length. Tripod or formal craniotomy scars are rarely seen and the predominance of linear scars allows approach to the skull defect in most cases through the original scar. In temporal bone defects, the usual craniotomy incision making complete or

partial use of sagittally directed scars and circumscribing vertical scars is indicated since the mass of muscle and the increased vascularity following injury in this region make direct exposure of the defect difficult. In frontal defects rostral to the hairline. coronal incisions are used. In the rare tripod scar, exposure of one angle of the former incision may be sufficient for insertion of the plate. Cranioplastic incisions about a horizontal scar should be avoided since they will be followed by incision-line necrosis. Rarely plastic revision of a broad, thin, scalp scar adherent to underlying tissue may be necessary before cranioplasty can be achieved.

After adequate exposure of the area of the skull defect by the means outlined above, its edges may be readily palpated. An incision is made through the pericranium about the edge of the defect 1 cm. from its margin. This pericranial tissue is resected centrally together with any excess extradural tissue over the area of the defect. Indicated bone resection, cerebral-scar resection, skull-fragment removal, dural repair, or other measures are carried out. It may be said at this time that nothing in the technic of tantalum cranioplasty precludes formal craniotomy at a later date.

To initiate the insertion of a tantalum plate, it is held provisionally over the defect and its margin altered if indicated with heavy cutting scissors so that it overlaps the margin of the defect for an approximate distance of 0.5 cm. This border is then marked by an ordinary dental scaler and to a depth of 2 mm. with the lineator, one of the simple instruments designed for this procedure (Fig. 31). This incision into bone at right angles to the surface of the skull forms the sharp inner border of the circumferential ledge about the border of the defect 0.5 cm. wide and 2 mm. deep, formed by a Stout No. 3 dental chisel. The pre-formed tantalum plate

Lineator

Stout No. 3 Chisel

Perforator

Wedge Director
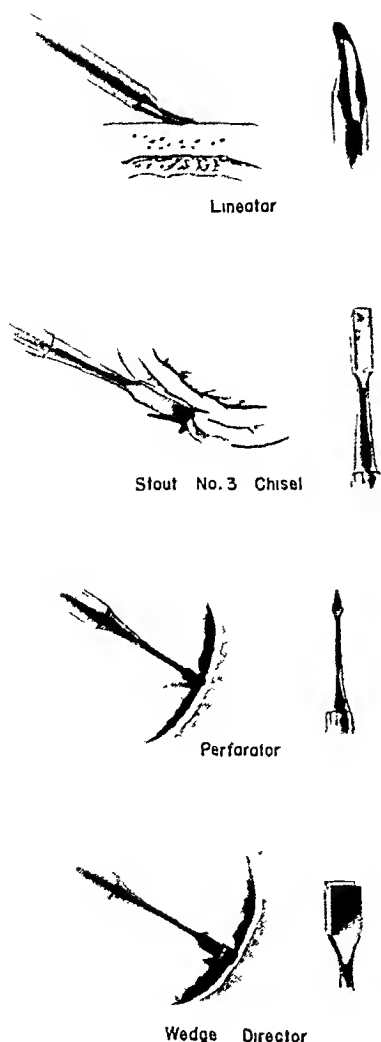
FIG. 31. Halftone drawing of instruments used in tantalum cranioplasty. (Courtesy, Jour. Neurosurg., 2:21–25.)

is then fitted into this ledge, its upper border flush with the skull, necessary adjustments being made with cutting scissors or minor contour changes with a contour pliers. With the plate held in this position by digital pressure, fixation is secured by means of tantalum triangular points much like glazier points. Seats for the tantalum wedges in the outer border of the bony ledge are made with a triangular pointed instrument, the perforator. The tantalum wedges, made of 0.020 inch plates, are tapped into place in the bone and turned inward over the edge of the plate with a wedge director. Four to six tantalum points may be used in any one case. Following insertion of the plate and closure of the scalp, a firm evenly distributed pressure dressing is applied (see Color Plate I).

Tantalum cranioplasty may be carried out as soon as primary wound healing has occurred and should not be deferred because of a history of pre-existing cerebral infection. Prior to operation prophylactic penicillin therapy is instituted with 30,000 units of penicillin being given every three hours for the 24 hours prior to operation. At the termination of the cranioplasty, 30,000 units are injected beneath the scalp incision and 15,000 units are given every three hours intramuscularly for the following three days. Similar chemotherapy is advisable in other types of cranioplasty.

The method which has been described is applicable to the majority of skull defects. An important variation which may have a wider application in the field of civilian neurosurgery consists of a preliminary direct impression of the proposed tantalum plate and its insertion at a secondary operation. The débridement of bone in acute injuries of the skull, the removal of a skull tumor, or the sacrifice of a bone plate at craniotomy may suggest the desirability at a later date of a secondary repair of the resultant skull defect. In suitable cases this plan may be facilitated by ledging the circumference of the bony defect as described above. An impression of the circumferential ledge with autoclaved dental compound is then made.

Prior to closure of the primary incision a sheet of tantalum foil 0.00025 inch thick is placed over the defect, extending well beyond the ledge. Repeated experience with

# PLATE I
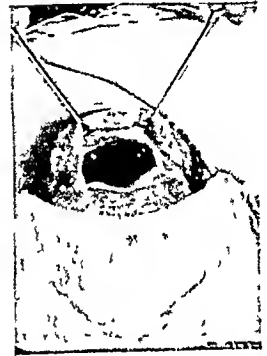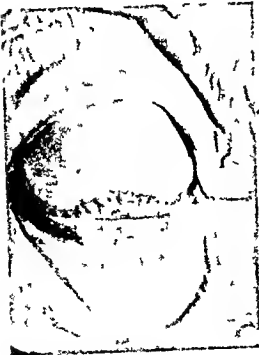


(A) Bifrontal skull defect from aerial torpedo fragment wound.
(B) Lateral view of bifrontal skull defect.
(C) Coronal scalp incision used for exposure of defects rostral to hairline.
(D) Exposure of skull defect after resection of pericranium about defect
(E) Preparation of circumferential ledge about defect prior to insertion of plate.
(F) Fixation of tantalum plate by means of tantalum wedges.
(G) Completed operative procedure.
(H) Frontal view of patient after tantalum cranioplasty.
(I) Lateral view of cranioplasty  Note restoration of frontal bone contour.

(Courtesy, Ann. Surg., 121:658, 1945.)

this method has shown that this is an important step in the technic of repair since at the secondary operation for the insertion of the plate the skull defect and adjacent bone will be found uninvolved in scar tissue and not adherent to the overlying scalp. The tantalum plate formed from the direct impression will need no adjustment at the secondary operation, and the procedure may be carried out expeditiously at any time deemed advisable during convalescence.

In addition to the two refined methods of cranioplasty that have been described, other methods are available for the repair of skull defects involving relatively uncomplicated skull contours. The preparation of these simple plates has already been described. Fixation methods include the simple onlay of the plate or inlay of the plate in a ledge, springing of the plate into the ledge, wiring or the use of screws, or the formation of V-shaped prongs as part of the plate and driven into the outer table of the skull as a method of fixation. Such simple methods have been used in tantalum cranioplasty of fresh war wounds, with the cranioplasty taking place at the time of the primary débridement. The principles involved may be applicable in fresh civilian wounds of the skull. Immediate cranioplasty of this type is possible only because of the low incidence of infection secondary to penicillin therapy and rightfully should be reserved for those cases without dural penetration. This procedure must still be considered to be in a state of clinical trial representing one of the efforts to hasten the convalescence of military casualties.

Considerable skill is required for the formation of tantalum plates designed to restore disfiguring and often repulsive frontal defects secondary to trauma or to the resection of osteomyelitic bone. Fastidious comparison of the wax restoration to the normal side or to earlier photographs of the individual patient will facilitate the accuracy of the restoration. In traumatic cases, the orbital contents may be lost on one or both sides, and in these tragic problems the ophthalmologist and neurosurgeon can correlate their efforts to advantage.

## SYNTHETIC RESINS

The place of acrylic resins in cranioplasty has not as yet been established although it is quite possible that the future development of these plastics may contribute materially to the evolution of the ideal cranioplastic substance. They are strong and inert in tissue but when prepared in the form of a plate they lack malleability. The plastic transplants are translucent to the x-ray and in incomplete clinical trials they have retained their contours during the period of observation. To insure the accurate molding of the plate, acrylic cranioplasty demands a direct impression of the cranial defect exposed at operation. The incision may then be closed and the restoration completed at a second sitting or the operative site may be protected for the time interval required for preparing the plate, usually one and a half hours.

After the impression has been made with wax or a combination of beeswax and petroleum jelly, a double dental stone or plaster dental stone form is poured in a standard sectional denture flask. The wax impression is boiled out, thus preparing the cavity to be filled with acrylic. The impression matrix is lined with 0.001 tin foil to prevent seepage of the material into the pores of the plaster. It is filled with the synthetic plastic in sufficient quantity to allow a packing pressure and considerable shrinkage. Gradual application of pressure allows excess material to escape, permits full closure of the mold, and compensates for shrinkage. The material is cured by immersing the entire flask in boiling water for 45 minutes. Either inlay plates, the full thickness of the skull, or onlay plates 2 to

3 mm. in thickness may be prepared by variations in the impression technic. Fixation in the former is obtained by wire sutures and in the latter preferably by metal screws. There is nothing specific about the postoperative care of acrylic cranioplasties.

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# 5

# Brain Abscess

## Edgar A. Kahn, M.D.

There is no single method of treatment applicable to all cases of brain abscess. This is obvious from the fact that these lesions differ in origin, location, and state of encapsulation. Moreover, the patients with brain abscess differ in general with varying degrees of increased intracranial pressure, edema, and, to a lesser extent, sepsis. With the present knowledge of the care of the acutely ill patient plus the use of penicillin and the drugs of the sulfonamide group, sepsis is no longer the factor that it was.

It is evident that one has no control over the origin of an abscess. The location of an abscess can be controlled only insofar as its depth is concerned. It is an axiom of surgery that the deeper an abscess lies the more difficult its approach and adequate drainage. It is thus fortunate that ordinarily by decompressing directly over a deep-seated abscess it will migrate to or above the surface of the brain because of the increased intracranial pressure.

It is now an accepted fact that the better encapsulated an abscess, the easier its successful drainage or excision. It is important that to a certain degree encapsulation can be controlled by studied procrastination.

I should like to consider briefly the origin, location, and state of encapsulation of cerebral abscesses, and the time of eradication of the original infective source. Treatment will then be discussed in the light of these factors, stressing the time and method of surgical treatment and the control of intracranial pressure and postoperative edema.

Newer chemotherapeutic methods are discussed in detail in Chapter 20.

## CEREBRAL ABSCESS

### Origin and Location

The majority of abscesses of the brain arise by direct extension from suppuration in the middle ear, mastoid, accessory nasal sinuses, or calvarium. Abscess of the temporal lobe and cerebellum is most prevalent in districts where considerable neglected mastoid disease is found. The acute purulent frontal sinusitis incident to swimming is a fertile source of frontal-lobe abscess.

Brain abscess is not infrequently found following neglected or improperly débrided compound fractures of the skull. These abscesses are invariably in the cerebral hemispheres. Brain abscess from the introduction of foreign bodies through war wounds will become more and more frequent. Brain abscess can also follow scalp infection without underlying skull fracture, by direct extension through emissary veins.

Metastatic abscesses, outside of those associated with a generalized pyemia, arise most frequently from pre-existing pulmonary abscess, empyema, or bronchiectatic cavities. This type of abscess is associated with anaerobic organisms and does not en-

capsulate, making drainage impossible. In our hands such cases have been invariably fatal, though cures have been reported by early excision of the infected brain substance.

Since the abscesses most favorable to surgical treatment arise by direct extension, a clue is provided as to the location of the abscess by the site of the previously existing infective source. Should a pansinusitis be followed by brain abscess, a lead come encapsulated, a period of relative quiescence usually follows the two- or three-day period of the symptoms of intracranial extension. In from ten days to two weeks, however, the headache returns and with it the signs and symptoms of increased intracranial pressure. Papilledema is then the rule except in abscesses of pulmonary origin where there is a marked destruction of brain tissue rather than a true expanding lesion.



FIG. 32. Metastatic abscess. This abscess is typical of the unencapsulated type metastatic from pulmonary abscess or bronchiectatic cavities.

is given as to which frontal lobe is involved by a history of a previous unilateral edema of the eyelids. If a frontal abscess is present it lies almost invariably on the side where the edema was previously noted.

The actual day of the intracranial extension can be frequently brought out by the history. The patient, who has been previously well except perhaps for a frontal sinusitis, otitis media, or bronchiectasis, suddenly becomes acutely ill with headache, vomiting, and stiffness of the neck which is associated with fever and leukocytosis. This onset may be accompanied by convulsions, especially where the primary source of infection is in the lung. In the case of an abscess which is destined to be-

In otitis media or mastoiditis, what determines whether the infection will travel directly to the overlying temporal lobe or extend posteriorly to involve the cerebellum? Though this question cannot always be answered, it can be stated as a general rule that if the osteomyelitic process extends through the tegmen tympani or mastoid antrum, the abscess will be found in the temporal lobe. Infection in the labyrinth or a lateral sinus thrombosus favors the cerebellum as the site for abscess formation. This can be established by trephining over the temporal lobe; if the exploring needle, instead of encountering the abscess, enters a dilated ventricle, the abscess will be in the cerebellar lobe of

that side. Where bilateral otitis media is present, localization may be more difficult. Here x-ray studies of the mastoids may be of value, the abscess usually lying on the side of greatest mastoid destruction. It should be kept in mind, as Courville and Nielson have pointed out, that the parietal and even the frontal lobes are occasional sites of otogenic abscess.

A careful neurologic examination is, of course, always essential, and may determine the diagnosis in many cases. However, where the location of the abscess cannot be established by ordinary means, one must resort to ventriculography.

### State of Encapsulation

There is among neurologic surgeons today a unanimity of opinion that the better an abscess is encapsulated the better the chance of surgical cure. It is for this reason that Vincent has proposed control of increased intracranial pressure by a decompressive osteoplastic flap with excision of the abscess after a period of weeks when the capsule has become sufficiently strong to permit its complete excision without rupture. Vincent has had considerable success with this method though it is not recommended for the surgeon not constantly practicing neurologic surgery. What the success of this method in his hands does stress is that if the increased intracranial pressure can be controlled until the abscess firmly encapsulates, the great majority of these abscesses can be cured.

Surrounding acute brain abscesses there is always a marked cerebral edema. It is this edema rather than the space-consuming lesion itself which results in localized neurologic manifestations and a generalized increase in intracranial pressure. This is easily demonstrated by giving hypertonic solutions over a period of, say, 12 hours, to patients acutely ill with brain abscess. The remarkable improvement commonly noted must be due to the reduction of the associ-

ated surrounding edema. This point has been impressed upon me by King.

The heavier an abscess capsule becomes, the less marked the surrounding edema and accordingly the better the patient's condition. Heavily encapsulated abscesses have been carried by patients for months before their discovery. Such abscesses have been removed under the mistaken impression that they were tumors, the wall at times measuring three-eighths of an inch in thickness. There has usually been comparatively little edema surrounding such abscesses. One might almost say that the degree of edema is inversely proportional to the thickness of the abscess capsule.

How can one determine the state of encapsulation of an abscess since the heavier the capsule the more easily it can be dealt with, and the less the edema the better the condition of the patient for surgery?

1. Time. The longer an abscess has been present the less the virulence of the organism, the greater the immunity of the individual, and the heavier the capsule. (The age of the abscess can generally be established by the history.) It has been shown experimentally that ten days may suffice for the capsule to become firm enough to give a sense of resistance to the dull exploring needle. (The invading organism may play some rôle here since the anaerobic organisms, such as those found in abscess metastatic from the lung, make no effort to encapsulate.)

2. Diminution in Signs and Symptoms. This suggests increasing encapsulation. Such signs and symptoms are temperature falling to normal or subnormal, decreasing leukocytosis, diminution or stabilization of papilledema, and a bettering of the general condition.

3. Lumbar Puncture. Though I feel that lumbar puncture is better to be avoided ordinarily, Woltman has shown that a small number of lymphocytes in the spinal fluid, in contradistinction to a larger num-

ber of polymorphonuclear cells, suggests optimal encapsulation. To sum up, two examples will be given:

I. A patient develops a severe head cold. Three days later a purulent frontal sinusitis develops with edema and complete closure of the right eyelids. Three days later severe headache, vomiting, stiffness of the neck, and photophobia appear. (This is undoubtedly the moment of intracranial extension.) A few days later the symptoms have subsided except for signs of subacute right-sided frontal sinusitis. Three weeks from the time the meningeal symptoms developed, headache increases and papilledema appears, and a slight left-sided facial paralysis of the central type is noted. One figures roughly then that the abscess is three weeks old, which is ordinarily sufficient time for the capsule to become firm enough to impart the "rubber-ball" resistance to the dull exploring needle. Drainage may then be carried out.

II. A patient is suffering from an acute frontal sinusitis. The sinus is probed. Thirty-six hours later signs of meningeal irritation develop. Three days later the meningeal signs have almost disappeared but the headache continues. The patient remains acutely ill. After ten days the patient becomes semicomatose, arousing at intervals. There is now noted a slowing of the pulse. Hypertonic solutions are given with considerable relief but this cannot be long continued for fear of producing a toxic dehydration. A trephine opening is made over the suspected frontal lobe. At a depth of 2 cm. a faint resistance is encountered by the dull exploring needle, following which pus is encountered. Marked relief results for ten days, following which headache and vomiting reappear. The capsule is now approximately 21 days old, probably adequately thick for surgical drainage. It would do no harm, however, to tap again and wait for symptoms to recur.

This is what is meant by studied procrastination in promoting increasing encapsulation of a brain abscess.

## TREATMENT OF INFECTIOUS SOURCE OF ABSCESS

In perhaps half of the cases of brain abscess which come to the neurosurgical clinic, the original infective source has been eradicated or at least drained by "medical incision." Attention then is focused upon treatment of the brain abscess, radical excision of the nasal accessory sinus or mastoid being reserved until later.

We formerly held that eradication of the bony source was essential before dealing with the abscess, provided that the patient was in comparatively good condition. The rationale was to prevent reinfection and to rule out epidural abscess as a cause for the symptoms.

Within the past few years, however, we have lost two patients within 24 hours of excision of the infective source and before drainage of the brain abscess—one following mastoidectomy and the other after a Killian operation. One of the patients was in excellent condition. Both died suddenly of an acute increase in intracranial pressure, and at autopsy the suspected abscess was found. In both cases ether anesthetic was used and intravenous fluids were forced postoperatively.

In osteomyelitis of the calvarium with underlying brain abscess, there is no doubt that the infected bone must be excised first. Where mastoiditis is present and one is not certain that a brain abscess underlies it (acute mastoid disease can produce a papilledema of up to one diopter plus meningism), the mastoid should be operated upon first. The same could apply to frontal sinusitis. However, given an acutely ill patient in whom the diagnosis of brain abscess is almost certain, it is probably better to deal with the abscess first. An inflexible rule cannot be laid down here.

OPERATIVE TECHNIC

There are certain basic principles in the treatment of abscesses of the cerebral hemisphere which should be constantly kept in mind and utilized in the individual case, if possible:

inject 4 or 5 cc. of colloidal thorium dioxide (thorotrast) into the cavity. Thus the exact location of the abscess can be established by x-ray studies before proceeding farther.)

3. Drainage of the abscess when the capsule is sufficiently thick.
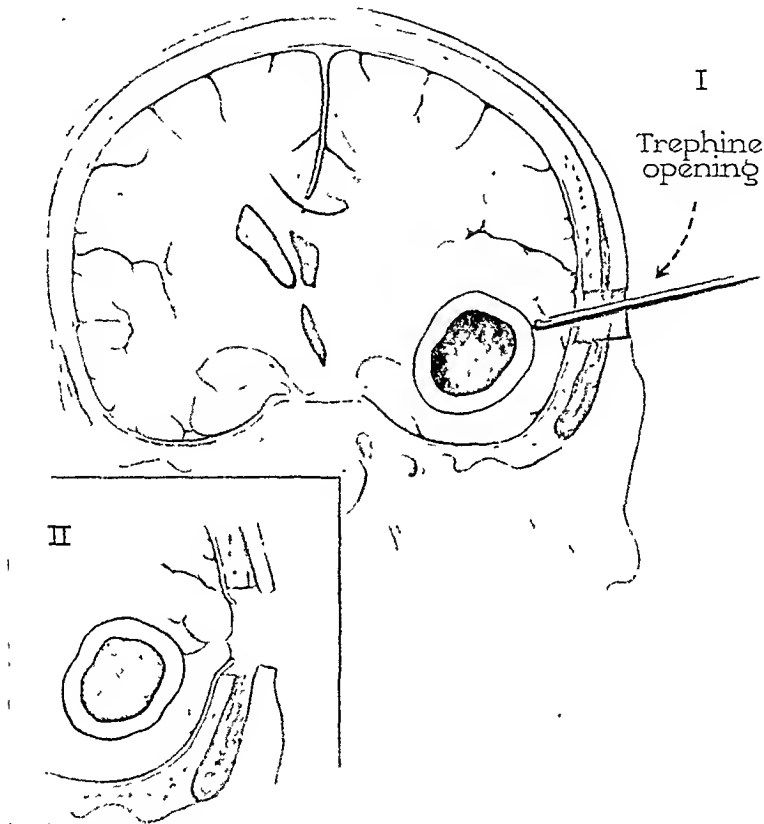


FIG. 33. Schematic drawing to show first stage of drainage of encapsulated brain abscess. (I) Abscess capsule is palpated with the dull exploring needle. (II) Bony opening is enlarged and dura opened further.

1. The control of increased intracranial pressure previous to drainage.

2. Accurate localization of the abscess with drainage at the point where it lies nearest the surface. (Should a deep-seated abscess be tapped unexpectedly, as in attempted ventricular puncture, it is ordinarily best after partially evacuating it to

4. Sealing of the meninges to the cortex previous to drainage.

5. Adequate drainage under direct vision.

6. Control of postoperative cerebral edema.

Let us consider that a diagnosis of abscess of the cerebrum has been made. If

the patient is extremely ill and shows signs of an acute increase of intracranial pressure such as stupor, and slowing of the pulse and respirations, hypertonic solutions should be given immediately. We or-

For suspected frontal abscess a transverse incision one and one-half inches in length is made approximately one and one-half inches above the eyebrow of the involved side, care being taken after study-
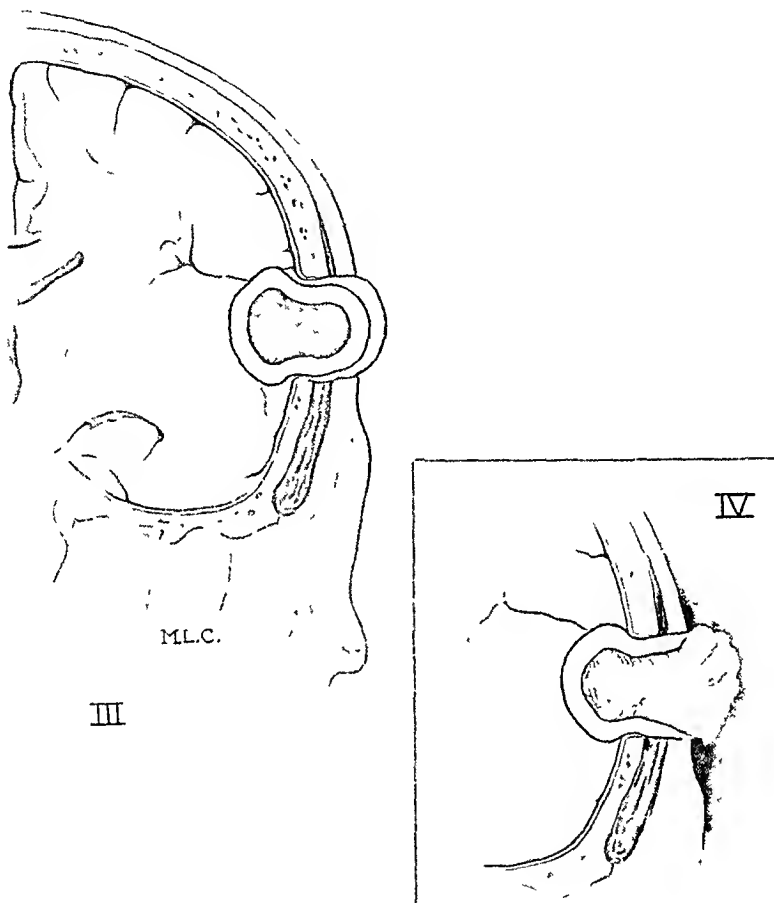


FIG. 34. Second stage of drainage. (III) Three to seven days later. Herniating brain substance has been removed. (IV) Dome of capsule has been excised and cavity loosely packed with gauze soaked in metaphen in oil.

dinarily give to the average-sized adult 100 cc. of 50 per cent glucose. This is repeated in from two to four hours, depending upon the patient's response. If the patient's condition does not improve, one must prepare to tap the abscess without further delay.

ing the x-rays to stay above the frontal sinus. For suspected temporal-lobe abscess, a vertical incision is made just above and slightly in front of the pinna of the ear. For abscess elsewhere in the cerebrum the incision is made directly over the suspected site. Local anesthesia is almost invariably

employed. If the patient is extremely restless, pentothal sodium intravenously is valuable.

The incision which has just been made is spread by means of a mastoid retractor. An opening about a half inch in diameter is now made in the bone. Any of the various trephine instruments may be employed, though we are partial to the Hudson burr. Bone wax is used to control hemorrhage from the diploic spaces only when absolutely necessary. The dura is picked up with a fine hook and incised. The pia arachnoid will herniate into the dural opening if there is any increase in intracranial pressure. This membrane is incised with a sharp knife as it is difficult to pierce with a blunt needle. One must be careful here to avoid surface vessels.

Again avoiding surface vessels, a blunt exploring needle, with stilet in place and preferably with visible centimeter markings, is passed through the brain substance in the direction of the suspected abscess. If the exploring needle encounters an encapsulated abscess more or less perpendicularly, there is imparted to the hand a feeling of resistance which might make one think that a hollow rubber ball had been indented. Penfield has shown experimentally in the dog that it takes at least ten days for the capsule to become sufficiently strong to impart resistance to the exploring needle. I have seen one case in the human in which this resistance was present ten days from the onset of cerebral extension. One should be cautioned that the exploring needle with its blunt end may strike the capsule obliquely and be carried along its side without any abnormality being noted. Thus more than one abscess amenable to surgical treatment has been overlooked.

If the abscess capsule is not encountered in the exploration through the trephine opening, one must "back out" for the time being. The worst mistake one could make
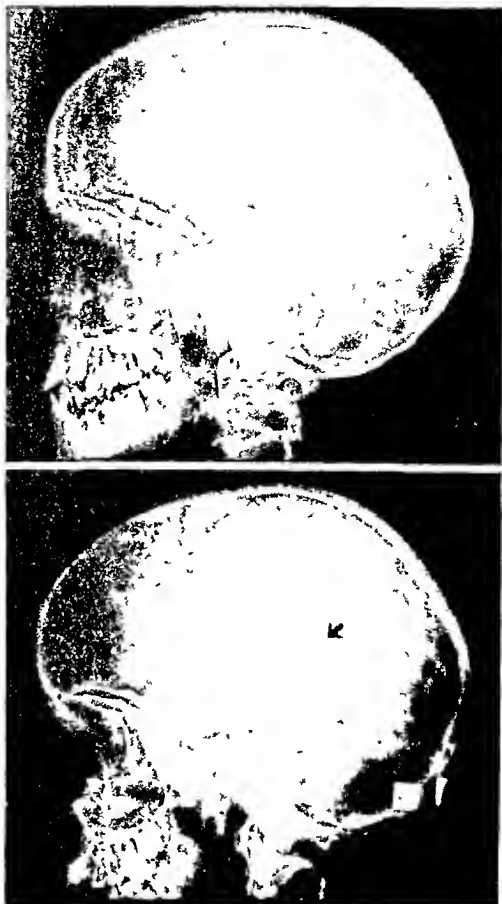


FIG. 35. Abscess of otogenic origin. (*Top*) Abscess was drained and 5 cc. of colloidal thorium dioxide (thorotrast) instilled. (*Bottom*) In this picture, taken 18 days later, the abscess has risen up to and against the decompression made four days previously. Arrow points to capsule which has phagocytosed the colloidal thorium and thus became radio-opaque.

would be to enlarge the bony opening and open the dura farther. The abscess might be hidden at some distance from the suspected site and all that would result would be a cerebral hernia. Therefore, if the abscess is not located definitely at first, the small incision should be closed and a trephine opening made over another sus-

pected area, or if there is no other area conceivable, ventriculography should be performed, unless it is deemed wiser to await further developments.

Let us now consider that the abscess capsule has been definitely located beneath the rongeur. The dura is further opened in a stellate manner. The cortex then herniates into the bony opening. The surface vessels are coagulated with the electrosurgical unit, if one can be obtained. During this procedure openings are made in
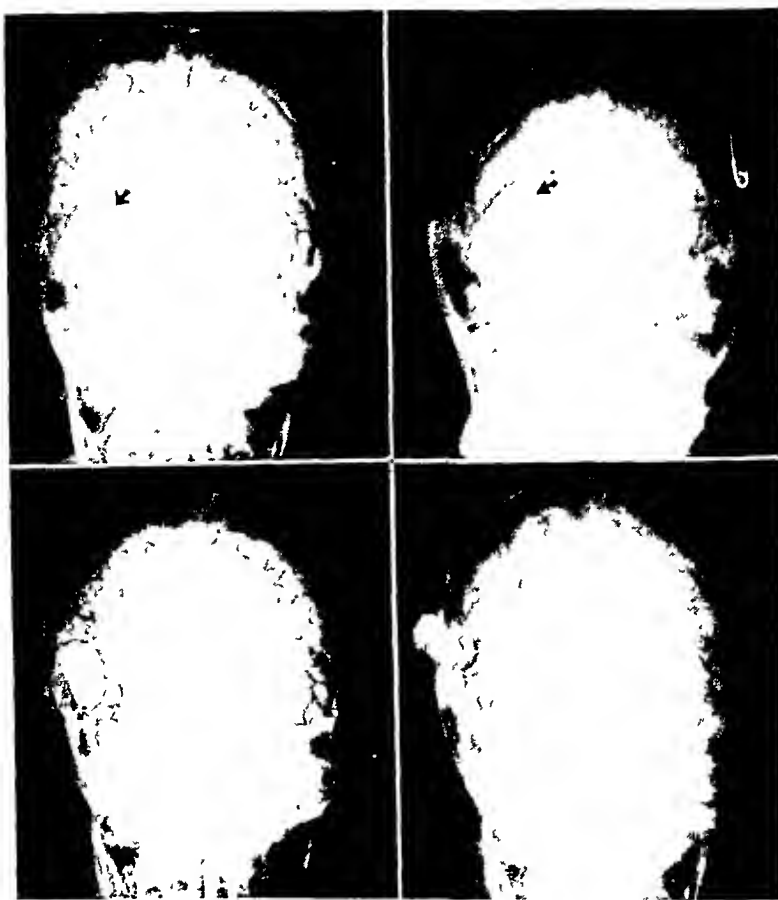


Fig. 36. Anteroposterior views of same case shown in Fig. 35. This abscess extruded spontaneously.

the cortex by exploration through a trephine opening. The next procedure depends upon the condition of the patient.

A. *The patient's condition is comparatively good:* The needle is withdrawn without entering the cavity. The scalp incision is enlarged to about two and one-half inches. The bony opening is enlarged to a diameter of one and one-half inches with the pia arachnoid to facilitate subsequent herniation. A pack of metaphen-in-oil is now placed over the wound and a loose but bulky dressing applied. The dressing is not disturbed for at least three days except that it may be necessary to change the dressings over the metaphen pack itself.

At the end of three or four days the metaphen pack is removed. The surface

vessels will be seen thrombosed over the herniating brain. The meningeal spaces in the immediate vicinity are obliterated, minimizing the danger of a meningitis.

By means of suction, the edematous brain substance is removed, any bleeding being controlled with electrocoagulation or silver slips. The firm, smooth, though somewhat vascular capsule will now be seen after one to two centimeters of edematous brain has been removed. (If the capsule lies deeper than this, one should replace the dressing and wait several more days until the capsule has migrated farther toward the surface. Adson and Craig have stated, "Cerebral abscesses are invariably situated below the cortex. Occasionally a stalk can be seen to extend from the meninges to the abscess, but more often than not no trace of invasion can be demonstrated.")

The capsule is now exposed over the entire bony defect. With a heavy-gauge needle the capsule is now pierced and the abscess sufficiently evacuated to relieve the marked tension. Following this an incision is made through the capsule, preferably with the electric knife. After more pus has escaped, the dome of the capsule is excised. A lighted retractor is then placed within the capsule and the base explored, all pus being removed by suction and pledgets of cotton soaked in hydrogen peroxide. (One rarely finds pocketing in an encapsulating brain abscess and one must never insert one's finger into the cavity to feel for such a pocket. The ventricle which invariably lies close imparts exactly this sensation to the exploring finger, and I have twice broken into it, unfortunately, before learning my lesson.) A pack of gauze soaked in metaphen-in-oil is then placed under direct vision in the dependent portion of the cavity, packing it loosely and bringing the end out through the defect. Several scalp sutures can then be loosely taken on either side of the pack to minimize the subsequent granulating area.

Postoperatively one should be on the lookout for an acute cerebral edema, although this rarely occurs in the patient who previously has not been extremely ill. Should this condition develop, it is manifested by increasing irritability or delirium, or slowing of the pulse and respirations with increasing stupor. This condition must be immediately combated with hypertonic solutions.

The dressing itself should not be changed for at least four days except to change the outer pads should they become soiled. At the end of four days the pack is superficially loosened and gradually withdrawn during the next three days. There is ordinarily but little purulent discharge. The granulating wound is dressed with gauze soaked in metaphen oil or petroleum jelly so that it will not adhere. Any herniation developing is easily controlled by lumbar punctures providing, of course, that another abscess is not present elsewhere. In any method of treatment, a second abscess lying at some distance from the first is the most feared complication and the one most difficult to handle. If the second abscess cannot be located and successfully drained, a fungus must develop and later death from purulent encephalitis. If the second abscess is close to the first, it will follow it to the surface, but ordinarily these multiple abscesses develop from a septicemia and are not only widely isolated but give no clue as to their various locations.

B. *The patient's condition is comparatively poor* but the abscess wall has been encountered with the dull exploratory needle and it is deemed that the abscess must be tapped immediately. The needle upon palpating the abscess wall is plunged into it. A culture is taken of the pus obtained. Pus is allowed to flow until it is

thought that the abscess is nearly evacuated. (One must be careful not to force the needle through the posterior wall of the abscess as it may enter the ventricle. This is always a shocking thing to do, but on the few occasions I have done so meningitis has failed to develop, making me believe that it is somewhat difficult to actually infect the ventricular system.) Aspiration is allowable if the pus is slowly

the abscess. A number of successful cases have resulted from this method though little is found in the literature about it.

The method consists in trephining over the suspected abscess and draining it as completely as possible after it has been entered. Should symptoms recur, the abscess is tapped repeatedly if necessary.

I have tried this method only a few times but have been invariably unsuccess-



Fig. 37. Abscess of otogenic origin. (A) This patient was extremely ill. Abscess was tapped and colloidal thorium dioxide injected and the decompression made 12 hours before x-ray A was made. It is obvious that the decompression was placed higher than it would have been, were x-rays taken first. (B) Three days later abscess has refilled and has migrated toward decompression so that excision of dome and packing of abscess cavity were easily performed.

withdrawn and too great suction is not used.

When it is thought that the abscess cavity is nearly empty, 4 to 5 cc. of colloidal thorium dioxide are instilled into the cavity, making certain that the needle is still within the abscess. The needle is then withdrawn.

One can now either decompress over the abscess, treating it from here on exactly as in Case A, or one can wait, following the refilling of the cavity by x-ray, and retapping or decompressing directly over the abscess at the proper time.

Dandy has advised repeated tapping of

ful. In all fairness, however, I have used the method in only those patients who were extremely ill.

In the first place I have done what I had thought was complete aspiration only to find at autopsy or open drainage that the abscess had been very incompletely drained. I have also found that subsequent attempts at aspiration were difficult and traumatizing and tended to produce a purulent encephalitis. This could be obviated, however, if at the first aspiration a small amount of colloidal thorium dioxide were instilled. The contrast medium would also be of aid in telling when the abscess

capsule has re-expanded sufficiently so that aspiration is necessary again.

Another advantage of using colloidal thorium dioxide in any form of treatment of a brain abscess is the fact that the particles are phagocytized by the cellular elements of the abscess wall, making the cap-

depth, colloidal thorium dioxide should be instilled into it after removal of some of the pus It will assuredly simplify the subsequent surgical procedure

## CEREBELLAR ABSCESS

Cerebellar abscesses are ordinarily small



FIG. 38. Deep-seated abscess. This abscess undoubtedly arose from the posterior ethmoidal cells. It was opened and drained just after the x-ray of December 10, 1941, was taken. Subsequent x-rays show collapsed capsule which is radio-opaque from colloidal thorium dioxide. Should this abscess reform it would be apparent in the x-ray studies.

sule itself radiopaque in three days or less Should the abscess collapse at the time of drainage and become "lost" in the depth of the brain substance, as not infrequently happens, there would be a considerable advantage in having the capsule radiopaque (Figs 38, 39). It is a good rule to follow that any time an abscess is unexpectedly entered with an exploring needle or is tapped at an unexpectedly great

in size and thin-capsuled Where the abscess extends into the pons, as frequently happens, the prognosis is much poorer than if the cerebellar hemisphere alone is involved.

The diagnosis as to the side of the lesion must be established before surgical treatment is instituted. This can ordinarily be done by history, neurologic examination, and ventriculography List and Johnson

have discussed lateralization of cerebellar tumors by ventriculography, and the same can be applied to abscesses.

Under local anesthesia an incision is made directly over the lobe involved at about the midpoint of the inferior nuchal line. The incision should be about two inches in length, and can be either vertical or horizontal. The underlying muscles are

passed inward and slightly medially for a distance of not more than one and a half inches.

Procedure 1. If the wall of the capsule is thin, a sense of resistance is imparted which is about that of the normal ventricular wall. Upon withdrawing the stilet, pus will appear. An attempt is then made to completely evacuate the abscess. Upon



Fig. 39. Anteroposterior views of same case. Great depth to which this abscess extends is shown.

split and retracted, exposing the occipital bone over a diameter of about one and one-fourth inches. An opening is made with the Hudson burr and this is enlarged with the rongeur over the extent of the exposure.

A small opening is now made in the dura which is ordinarily found to be under marked tension. This tension is desirable and will aid in sealing off the meninges, thus preventing submeningeal spread.

The cerebellar cortex which is seen bulging through the dural opening is now touched with the electrocautery or else a small incision is made into it with the ordinary knife. A dull exploring needle is now

withdrawing the needle the point of entrance on the cerebellum is touched with the electrocautery or an antiseptic solution. A small amount of sulfanilamide is then dusted over the incision, a pack of metaphen-in-oil is placed over the dura, and the scalp loosely closed over it with one layer of sutures. The pack is removed in approximately five days. Should symptoms not be relieved or recur, it may be necessary to retap the abscess or resort to open drainage, as will be described in procedure 2. The appropriate drug of the sulfonamide group is, of course, started as soon as possible.

Procedure 2. If the wall of the abscess

capsule on exploratory puncture imparts a firm sense of resistance to the cannula, like that of a rubber ball, it is better in my opinion to resort to open drainage. The cannula is still plunged into the cavity and enough pus obtained to relieve pressure for the time being without completely evacuating the abscess. The needle is then withdrawn and the dura opened in a stellate fashion. A pack of metaphen-in-oil is then placed over the dural opening and allowed to remain for from three to five days, during which a sealing off of the meninges will have taken place, no attempt being made to close the scalp wound.

When the pack is removed at the end of this period, the cerebellar cortex is removed by electrosurgical excision and suction, exposing the dome of the abscess capsule. The dome is then excised and all pus removed from the cavity under direct vision. A pack of metaphen-in-oil is then placed within the cavity and the scalp loosely sutured around to shorten the period of healing of the wound. Removal of the pack is commenced in from five to seven days.

## POSTTRAUMATIC ABSCESS OF BRAIN

A distinction must be made between the encapsulated posttraumatic abscess and the lesion found a few days or weeks after incomplete or nondébridément of a penetrating brain wound. In these cases there is an accumulation of pus and broken down brain and, as a rule, retained bone fragments. It is most difficult at times to differentiate between frank pus and broken-down brain. The question arises, "Is this an abscess or is it a localized cerebritis?" The difference is only one of terminology. True encapsulation is not present. In the depths of the amorphous mass there is a gradual blending with the uninvolved brain substance.

Treatment consists of prompt and radical secondary débridément with tight closure or drainage depending upon the amount of frank pus found, the odor and, more than any other factor, the preference of the individual surgeon. Many of these cases have been closed tightly with primary healing. One such case operated upon by Schwartz thirty-two days after injury was closed without drainage and healed primarily.

Abscesses due to penetrating wounds of the brain will increase as the present conflict assumes larger and larger proportions, and for some time after the war cerebral abscesses will continue to appear from retained foreign bodies.

Such abscesses invariably appear along the tract which the foreign body has made. The abscess, itself, is less apt to form about a metallic object than the bone fragments, hair, or clothing which have been introduced. The reason for this, of course, is the fact that the metal shell fragment travels at terrific speed and generates sufficient heat to become self-sterilizing. In the prevention of infection in such a wound it is, therefore, of more importance to thoroughly débride the tract than it is to remove the metal fragment.

The diagnosis in such a case should be comparatively easy. Demonstration of the scar of the wound of entrance plus x-ray studies of the foreign body should establish the tract along the course of which the abscess must lie.

The posttraumatic abscess of the brain is usually more irregular and more tubular or elongated in form than that of otogenic or nasal accessory sinus origin. In my opinion, the reason for this lies in the fact that the capsule of a posttraumatic abscess is laid down as a cast of a portion of the sinus tract, the gradually expanding lesion retaining this form. This type of abscess tends to have a more heavily fibrotic type of capsule. Penfield and Buckley have shown in dogs that the amount of intracerebral scar in puncture wounds of the

brain varies directly with the amount of injured cerebral tissue which has been left behind. It is probably this same injured cerebral tissue in penetrating wounds improperly débrided which so increases the thickness of the abscess capsule.

Since the posttraumatic abscess is irregular in form, thick-capsuled and often loculated, tapping or tube drainage is an unsatisfactory method of treatment. For the same reasons this type of abscess is not apt to migrate superficially when a decompression has been made over it.

If a draining sinus is present with underlying osteomyelitis, the latter should be excised. Since the abscess lies beneath, all infective material should be removed before the abscess itself is attacked, providing that the patient's condition is not precarious, in which case drainage of the abscess must be performed at once.

Ordinarily if an area of osteomyelitis is present, it is excised into healthy bleeding bone. An opening is then made in the dura and a pack of metaphen-in-oil placed over the cortex to seal off the meninges. Several days later the abscess is located by exploratory puncture, sterilizing the site of puncture with the electrocautery. The overlying cortex is now excised electrosurgically until the dome of the abscess is widely exposed. The latter is then uncapped and the cavity explored under direct vision. A lumbar puncture may now simplify this exposure. All pus is removed by suction and the interior of the abscess further explored for loculations. Again one is cautioned against exploration with the finger.

If the capsule is exceedingly thick, it may be necessary to excise the greater part of it with the electrosurgical loop. To avoid breaking into the ventricle it may be advisable to leave the medial-most portion of the wall to act as a barrier. Where excision has been carried out, a pack of metaphen-in-oil is loosely placed in the dependent portion of the cavity; otherwise the abscess capsule is packed with gauze soaked in metaphen-in-oil. The scalp is loosely sutured around the pack which is left in situ for seven days, following which it is gradually withdrawn. One of the drugs of the sulfonamide group is always given by mouth and is preferably started the day before operation.

## ACUTE SUBDURAL ABSCESS

Acute subdural abscess is almost invariably a complication of an exceedingly virulent frontal sinusitis. Although this condition is comparatively rare, it is a definite entity and differs from those cases in which subdural pus spreads slowly or remains circumscribed beneath an area of osteomyelitis.

In acute subdural abscesses the picture is a most fulminating one. The usual story is that of a severe frontal sinusitis followed in a few days by the signs of intracranial extension. This is followed within a week's time by a progressive hemiparesis in an individual who appears far more toxic than the usual patient with early brain abscess. The hemiparesis is found to be more marked in the arm and face than in the leg, suggesting a diffuse cortical lesion in contrast to the complete paralysis or equal involvement of the extremities of the hemiplegic side seen in lesions of the internal capsule.

The picture presented by acute subdural abscess could scarcely be confused with the ordinary brain abscess, although a purulent encephalitis would have to be considered. The differential diagnosis is easily made, however, by an exploratory trephine in the frontal region, pus gushing forth upon opening the dura.

X-ray studies are of little help in the diagnosis of a subdural abscess outside of the demonstration of a frontal sinusitis. The infection moves so rapidly that even were an osteomyelitis of the frontal bone

above the sinus present it would ordinarily be too early to be demonstrable by x-ray.

Leukocytosis in these cases will vary between 20,000 and 30,000. The temperature remains elevated. Should a lumbar puncture be performed, the pressure will be found to be markedly elevated. A cell count as high as 5,000 may be found but no organisms will be demonstrable by smear or culture unless the infection has broken through the arachnoidal barrier, in which case a true meningitis rather than a meningism would be present.

Out of approximately a dozen cases which we have seen, all have resulted fatally with the exception of two. In the first of these, almost the entire frontal and part of the parietal bone was removed and the dura widely opened. The resulting defect and brain scar were so extensive that the patient might better not have recovered. The second case was more efficiently though less radically handled and the excellent result leads me to believe that others can be cured. This case will be presented in some detail because of several lessons which it points out.

A boy aged 17 entered the University Hospital with the following history: Two weeks previous to admission the patient had suffered an ordinary head cold. This began to subside within a few days but bilateral frontal headache persisted. One week before admission the headache became more severe on the right and swelling of the right upper eyelid developed rapidly. Two days later the swelling had reached a peak and rapidly subsided. There was now noted, besides increasing headache, stiffness of the neck and increasing irritability. Two days before admission nausea and projectile vomiting developed and numbness of the left hand was complained of. This was rapidly followed by weakness of the entire left side.

Examination revealed an extremely ill and apathetic patient. The temperature was 103°, pulse 78, and respiration 20. There was stiffness of the neck and a positive Kernig's sign. Fundoscopic examination revealed early papilledema. There was a left central type of facial paralysis and the tongue deviated to the left on protrusion. There was weakness of the left arm and slight weakness of the left leg. Babinski's sign was negative bilaterally. There was a leukocytosis of 20,000. A pansinusitis on clinical examination was confirmed by x-ray studies.

A diagnosis of subdural abscess was made. Inasmuch as the infection was thought to have extended through the right frontal sinus, epidural pus was also suspected. It was decided to first perform a right-sided Killian operation.

At operation an empyema of the right frontal sinus was found. The entire wall of the frontal sinus was removed but there was no evidence of erosion of the inner table. The ethmoidal cells were found to be grossly infected and were exenterated. The anterior face of the sphenoid was removed and the sphenoid found to contain thick pus. The inner table of the frontal sinus was removed but there was, in this case, no evidence of epidural pus or even granulation tissue over the tense dura. It was thought best to expose the dura through a clean field above .the operative site. It was believed that the patient's condition warranted waiting until the following day before carrying out this procedure.

The patient was carefully watched for the next 24 hours since any further evidence of acute increase in intracranial pressure would have necessitated immediate operation.

. At the end of this period the patient's condition was unchanged. Under local anesthesia a trephine opening was made over approximately the center of the frontal bone. The dura appeared tense and whiter than normal. Upon opening the dura there was an escape of a large amount

of thick, greenish-white, odorless pus which was extra-arachnoid. The incision was now enlarged and an area of bone about the size of a silver dollar removed with the rongeur. The dura was further opened in a stellate manner, the pus extending in all directions. There now developed a herniation of the brain through the defect, making retraction of the brain impossible. In order to gain relaxation so that all pus could be removed and adequate drainage established without making a tremendous bone defect, it was decided to perform a lumbar puncture.

The patient was turned and the lumbar-puncture needle introduced. The pressure was between 600 and 700 mm. of water. The fluid was cloudy and contained 5,600 cells per cmm. After approximately 50 cc. had been obtained the brain commenced to pulsate and to drop away from the dura. Leaving the lumbar-puncture needle in place the surface of the brain was now easily depressed with a lighted retractor, the entire surface of the brain being explored back to at least the midparietal region. All pus was removed by suction even as far forward as the tip of the frontal pole. The wound was washed out with Ringer's solution and hydrogen peroxide, inasmuch as it was thought that the pus could not be·extended any farther than it had already gone. Rubber tissue drains were inserted as far as possible in four directions—to the postparietal region, the midline, the tip of the frontal pole, and down onto the temporal lobe near its tip. This procedure was carried out without difficulty and with almost no trauma to the arachnoid since the hemisphere following lumbar puncture retracted from the dura for at least 1.5 cm. in all directions. The drains were gradually removed within the course of the next four days. Convalescence was comparatively uneventful; the mild herniation noted at times was controlled by lumbar puncture until granulation was complete.

To sum up, the following are the principles in the treatment of acute subdural abscess: (1) Excision of the infective source if possible, and (2) drainage of the subdural space through a bony defect which is just adequate for thorough drainage in all directions. This may be greatly facilitated by lumbar puncture after the dura has been opened, the atmospheric pressure aiding in retracting the brain over the entire hemisphere.

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# 6

# Osteomyelitis of Skull

James H. Maxwell, M.D.

Osteomyelitis of the skull continues to offer a direct challenge to the diagnostic acumen, the surgical judgment, and the technical ingenuity of the neurosurgeon and rhinologist. The most outstanding and comprehensive early contribution to the present knowledge of this disease, particularly in its relation to suppurative processes in the pneumatic spaces of the skull, was made by McKenzie[1] in 1913. Interest in the subject has been stimulated by expressions of divergent opinions relative to various phases of the disease. The publications of Bulson,[2] Skillern,[3] Lillie,[4] Hastings,[5] Woodward,[6] Adson and Hempstead,[7] Willenski,[8] Bucy and Haverfield,[9] and others, and outstandingly those of Furstenberg[10] and Mosher and Judd[11] have served collectively to enrich our understanding of this rare but important disease.

## GENERAL TYPES OF INFECTION

### DESTRUCTIVE LESIONS

For clinical purposes, cases of osteomyelitis of the skull may be divided into those of fulminating, rapidly spreading character, and those in which there is a tendency to localization and sequestrum formation. Such a classification, though practical, disregards the many vagaries of this unpredictable disease without due consideration of the etiologic background, the type of infecting organism, or the preparation of the soil. Clinical experience offers convincing evidence that the above classification permits of a practical division of cases for the surgeon whose plan of attack depends upon the rapidity with which the infection invades the diploetic structure of the calvarium. However, one must be cognizant of the fact that an area of osteomyelitis that seems to be showing signs of localization and self-limitation may at any time begin a rapid and devastating spread. In fewer instances the converse situation may be encountered; that in which the early sepsis and spreading edema has prognosticated a rapidly spreading infection, but localization, at least temporary, is effected by the formation of local barriers.

### PROLIFERATIVE LESIONS

In rare instances and for reasons unknown, the osteogenetic properties of the periosteal connective tissues are stimulated by long-standing low-grade inflammatory processes. In such an event the pyogenic destructive process is minimal and greatly outdone by an apparent reparative process which may produce new bone to the extent of tumor formation (Fig. 40).

## ETIOLOGY

Age. Most of the reported cases have been in the third and fourth decades of life.

Sex. There is no convincing proof that there is any sex predilection.

1. Paranasal-sinus Suppuration. Acute fulminating infection in the sinuses, and particularly in the frontal sinuses, may eventuate in the spread of the process to the diploe. This type of infection may be caused by swimming and diving, and occasionally it is encountered in measles and scarlet fever. The few cases of osteomyelitis of the skull, as compared to the many cases of acute sinus suppuration, tend to prove that such a complication occurs in rare instances. In considering the



Fig. 40. X-ray demonstrating proliferative osteomyelitis with tumor formation. Tremendous thickening of frontal bone is clearly visible.

fulminating sinus infection due to swimming and diving, it has been expressed previously by the author[12] that the immediate complications are more likely to be intracranial than calvarial.

2. Surgical Operations upon Infected Paranasal Sinuses. Although there is some controversy regarding the advisability of performing surgical operations in cases of acute sinusitis, the dictum "avoid bone work in the treatment of acute sinusitis" should be observed except in the rarest instances. Fulminating osteomyelitis of the

skull may be precipitated by the execution of surgical procedures during the acute phase of an infection. An analysis of reported cases demonstrates this point very clearly. There is no one type of sinus operation to be condemned particularly. Simple trepanation of the frontal sinus, either through the floor or through the anterior wall, with special care to avoid removal of mucous membrane in cases of acute frontal empyema, has yielded excellent results in the hands of some rhinologists. This type of operation seems least likely to invite the ravaging effects of the spread of infection to the diploe. Probably the most inordinate of procedures in such an acute suppuration is the intranasal drainage of the frontal sinus or ethmoidal labyrinth. An incomplete excavation of these sinuses by the external route is equally deplorable. When, because of epidural abscess, subdural abscess, meningitis, or brain abscess, an operation upon the sinuses becomes imperative, the operation should be done by the external route and should be done completely, in an effort to prevent the occurrence of osteomyelitis.

3. Mastoiditis. In rare instances a spreading osteomyelitis of the calvarium may complicate a mastoiditis. Such a condition may be a sequel to an incomplete operation in the case of a fulminating acute infection (Figs. 41, 42), or it may occur without previous surgical trauma. Localized osteomyelitis of the occipital bone, associated with a perisinuous abscess, is not uncommon; and its eradication during the course of a complete operation upon the mastoid usually serves to effect a cure.

4. Trauma. Various types of skull injury, from compound fracture to the trauma produced by the Crutchfield clamp, may cause spreading osteomyelitis. Even an infected scalp wound without apparent periosteal injury may precipitate a spreading diploetic suppuration (Fig. 43). Occasionally skull injuries, with or without

fracture, may incite a proliferative osteomyelitis.



Figs 41 and 42. Radiographs demonstrating extensive removal of bone for osteomyelitis complicating mastoiditis. Bone removal included posterior rim of foramen magnum and postsigmoid cells of contralateral mastoid.

It is generally believed that osteomyelitis of the skull resulting from trauma is a less fulminating process than that following nasal accessory-sinus disease. The apparent reason for this is that the organisms introduced are usually less virulent than those harbored in the nasal accessory sinuses. The tendency to sequestrum forma-



Fig. 43. X-ray film of skull taken two months after scalp laceration due to human bite.

tion in this type of lesion may be due to comminution at the fracture site, which interferes with the blood supply of the separate fragments.

**5. Blood-stream Infection.** Metastatic foci of osteomyelitis in the skull produced by septic emboli in the blood stream are rare, but may be produced by certain blood-stream infections. Their occurrence may occupy any portion of the calvarium Of general interest are those cases secondary to a septicopyemia. The osteomyelitis of typhoid fever and syphilis are specific types of blood-borne infections.

## BACTERIOLOGY

Pyogenic cultures commonly reveal the *Staphylococcus aureus* or *Staphylococcus albus*. The hemolytic streptococcus or occasionally the *Streptococcus viridans* may be found. The presence of the latter is rare but gravely important.

Williams and Heilman[13] and Galloway[14] have contended that anaerobic streptococci are the primary invaders in many cases of cranial osteomyelitis. Galloway has recovered these organisms from many such infections and believes from his experience

that their presence may account for some of the unusual aspects of this disease.

## PATHOLOGY

Osteomyelitis is by definition an inflammation of the bone marrow, or of the bone and marrow spaces. As with other types of inflammation, it may be acute, subacute, or chronic. In the acute phase one finds evidence of the exudative character of inflammation; namely, an excess of fluid and inflammatory cells, usually polymorphonuclear leukocytes, in the marrow spaces. In this phase there is frequently evidence of bone destruction as a result of the activity of osteoclasts or osteolytic enzymes. In the subacute phase first evidence of reparative processes are encountered and these are characterized by the appearance of fibroblasts and angioblasts in the marrow spaces, although all of the characteristic evidence of the acute phase may still be present. In the chronic state, adult fibrous connective tissue in some of the marrow spaces is found, and new and irregularly arranged small masses or cords of bone may be present as the result of the activity of osteoblasts. Again, all of the evidence of the acute phase may persist, and in the zone between the purulent exudate and the mature connective tissue fibroblastic and angioblastic proliferations become manifest. Thus, in chronic osteomyelitis, purulent exudate in the marrow spaces associated with bone destruction or osteolysis may be occurring in one area, while adult connective tissue and irregularly arranged spicules of new bone are being produced in another. In many instances spicules, or larger fragments of bone, are cut off from their blood supply and undergo necrosis, which accounts for the production of sequestra.

As the healing processes of the chronic phase of osteomyelitis proceed, more and more connective tissue, essentially scar tissue, is found in the marrow spaces; and more and more new bone is formed. When the formation of new bone predominates in the healing of bone, the structure becomes very compact and hard, and the process by which this hard bone is formed is called sclerosis or eburnation.

Under some circumstances in osteomyelitis, an overproduction of granulation tissue (inflammatory cells, fibroblasts, angioblasts, and vascular adult connective tissue) occurs in the same way that exuberant granulation tissue forms in other types of infection. In the bones of the skull, such as the wall of one of the nasal accessory sinuses, the excess of granulation tissue is, for obvious reasons, not controlled as it is when it occurs in a surface wound. In the process of repair or healing of such exuberant masses of granulation tissue, scarring and new bone formation frequently take place. The growth of the new bone may have a final pattern which somewhat resembles the shape assumed by the granulation tissue itself. Not infrequently this atypically placed mass of new bone will have the appearance in the roentgenogram, and at the time of operation, of an osteophyte or an osteoma. In the majority of instances these bony excrescences should not be designated osteomata, since they will continue to enlarge only as long as chronic inflammation continues to cause the production of granulation tissue and new bone. In other words, the bony growth is dependent for its continued development upon the presence of active chronic inflammation, while in the case of a true osteoma growth continues in the absence of any known exciting factor. In these cases the atypical bony masses are most accurately designated as areas of chronic productive osteomyelitis with a formation of osteomatoid excrescences. It is of course possible that a true tumor of bone occasionally has its inception in the continued irritation incident to a chronic osteomyelitis. However, such instances are probably rare, and care-

ful appraisal of the histologic pattern in the bony nodule will be required to make proper naming of the process possible. In a few instances, even in the presence of an accurate history and careful pathologic examination of excised material, it may be impossible to differentiate the bony mass resulting from a chronic productive osteomyelitis from that of a true osteoma with evidence of active chronic inflammation on or near its surface.

## METHOD OF SPREAD OF INFECTION

The mode of extension of infection from the frontal sinuses to the diploetic structure of the calvarium, and from one part of the calvarium to another, has been the subject of much discussion in recent years. The rôle of continuity and contiguity of tissue is obvious. The importance of the venous channels in the diploe and of the emissary veins extending from the mucous membrane of the sinuses to the dural veins was brought to our attention by Furstenberg[10] and Mosher.[11] The type and virulence of the infection in its relation to the natural and acquired local barriers determine the method of spread in each individual case. In many instances there is evidence of direct extension from the sinus into the diploe and spread of infection through the diploic channels. In others, and this is especially true in cases of fulminating sinusitis such as those due to swimming and diving, an epidural abscess may develop under an intact posterior wall of a frontal sinus, and by retrograde thrombosis produce an osteomyelitis of the inner table of the skull at some distance from the margin of the frontal sinus. Even after the osteomyelitic focus is established, thrombophlebitis of the dural veins and retrograde thrombosis may serve to produce another osteomyelitic lesion at some distance from the primary focus. Knowledge of this possibility is important to the

surgeon when he is attempting to delineate the area of the skull to be removed in an effort to eradicate the disease.

## CLINICAL FINDINGS

In most cases the history will be that of an acute exacerbation of a chronic purulent sinusitis, an acute fulminating sinusitis, or, too frequently, a recent partial excavation of the frontal or ethmoidal sinuses during an acute phase of the infection. More rarely there may be a history of trauma.

The patient presents the picture of an acute sepsis. Fever is present, the temperature varying between 101° and 104°F., and there is a polymorphonuclear leukocytosis, usually between 15,000 and 25,000. Signs of slight meningeal irritation may be elicited after careful search. The local symptoms are those of pain, which is regional in the absence of intracranial complications. Hemicrania or pain over a wide area beyond the obvious focus suggests the possibility of an intracranial extension of the infection. Shaking chills, changes in the sensorium, visual disturbances, and nausea and vomiting likewise indicate a spread of the infection to the meninges, dural sinuses, or brain.

Examination reveals a pitting, puffy edema of the scalp and exquisite tenderness in the area of the external swelling. Since an infected frontal sinus is the most common primary focus, there is usually prominent swelling of the upper eyelids. Conjunctival chemosis and proptosis, due to orbital cellulitis, are not unusual findings. Early, within a few days after the onset of the disease, a subperiosteal abscess may occur, due to the formation of a bone abscess and destruction of the outer table. Pain and tenderness to percussion beyond the area of the external swelling, particularly if the external swelling is not proportionate to the patient's acute sepsis, may indicate an epidural abscess.

The signs and symptoms vary greatly, depending upon factors which control the spread of any suppurative process. The findings which have been presented are those usually encountered in a rapidly spreading infection. In the case of one of low virulence, in a patient whose defense mechanism tends to wall off the focus, there may be minimal signs of sepsis. The temperature may be normal or tend to show only slight variation. Leukocytosis may be absent. External swelling may be limited to a small area immediately over a minimal osteomyelitic focus, and during a period of days or weeks a localized subperiosteal abscess may be formed. Likewise, in cases complicated by an extension through the posterior wall of the frontal sinus due to a septic thrombophlebitis, a small epidural abscess may develop and remain quiet for varying periods of time, and then gradually produce a localized osteomyelitic process in the inner table. Here again, regional pain and tenderness beyond the boundaries of the sinus after clinical evidence of sinus suppuration has subsided, and even in the absence of external swelling, should excite the suspicions of the examiner.

It must be reiterated that there is no real line of demarcation that separates these infections showing a tendency to localization and sequestrum formation from the fulminating types. The presence of the infection demands prompt and radical treatment since an apparently localized process may suddenly break its bounds and show evidence of rapid and devastating spread.

Since the advent of the sulfonamide drugs and penicillin, more cases of localizing osteomyelitis have been encountered. After conservative treatment by chemotherapy and repeated minor surgical procedures during a period of weeks or months, the disease tends to recrudescence with desolating effects.

## RADIOGRAPHIC FINDINGS

Radiography of a well-established osteomyelitis of the skull demonstrates the classic picture of an irregular area of erosion of the skull which suggests a motheaten appearance (Figs. 44–46).



FIG. 44. Extensive osteomyelitis of frontal and parietal regions showing characteristic motheaten appearance of bone as seen in x-ray film.

Careful x-ray studies should be made in every suspected case, but surgical therapy must not be delayed by waiting for positive roentgenograms. Films taken early in the disease give valuable information regarding the size, shape, and pathologic changes within the sinuses; and if positive evidence of osteomyelitis is obtained, of course their value is enhanced. Occasionally an area of rarefaction due to change in the inner table can be detected by x-ray when there is no external swelling.

## DIAGNOSIS

Diagnostic criteria for advanced osteomyelitis are well established. The signs, symptoms, and radiographic findings are classic.

Beginning osteomyelitis—that is, during the first two or three days of the invasion of the diploe—presents a diagnostic problem that tests the sagacity of a shrewd clinician. One must remember that swelling of the eyelids and of the soft tissues in the region of the inner canthus accompanying an acute frontal and ethmoid sinusitis does not indicate, necessarily, the beginning of a spreading osteomyelitis. Such a swelling may signify only an orbital cellu-

squama below the lateral angle of the frontal sinus is of especial significance.

No discussion of the diagnosis of osteomyelitis of the skull, and particularly that of the frontal bone, would be complete without due consideration of epidural abscess. An accumulation of pus on the surface of the dura may be the result of destruction of the inner table in an established case of osteomyelitis. In such an instance, the symptoms produced are



Fig. 45. X-ray findings in same case shown in Fig. 44, demonstrating extent of bone removal.

Fig. 46. X-ray taken year after that shown in Fig. 45 to demonstrate plaques of regenerated bone.

litis, a peri-orbital abscess, a periosteitis, or even an erysipelas.

There is always sufficient time in which to make a diagnosis, providing that time is utilized to full advantage. If signs of sepsis increase, if the orbital contents can be excluded as the cause of the external manifestations, and if during two or three days the pitting puffy edema extends on the forehead well beyond the limits of the clouded frontal sinus as demonstrated by radiograph, the diagnosis of a spreading osteomyelitis of the frontal bone becomes tenable. Pain and tenderness to percussion over the frontal bone or the temporal

closely linked with those of the overlying bone lesion and the diagnostic problem is not acute, since the bone infection presents its own indications for surgical operation during which the epidural pus will become manifest. Most important is the epidural abscess which develops beneath an intact inner table. Such an occurrence is due to septic thrombophlebitis of the dural veins and it may be the result of very early extension of infection through the intact posterior wall of an acutely infected frontal sinus. Thus one can account for the signs of meningeal irritation during the first two or three days of a fulminating sinusitis, at

a time prior to the development of a sinus empyema. Also, such an abscess may occur at some distance from the apparent edge of an established osteomyelitis, due to the spread of infection by retrograde thrombophlebitis of the veins on the surface of the dura, as described by Furstenberg.[10]

When the abscess lies under an intact posterior sinus wall, its presence must be determined in order that it may be evacuated and the extension of infection to the leptomeninges and brain substance thus prevented. Diagnosis may be exceedingly difficult due to the absence of localizing neurologic signs. Careful evaluation of the history, thorough examination of the patient, and intelligent observation frequently will serve to allow a positive diagnosis in the face of equivocal clinical findings. Some helpful diagnostic hints are as follows:

1. Evidence of meningeal irritation during the first few days of a fulminating sinusitis, especially one that has been caused by swimming and diving.

2. Tenderness to percussion over the frontal bone beyond the limits of an infected frontal sinus, in the absence of edema of the forehead.

3. Continued evidence of undrained pus, as manifested by fever and leukocytosis, in a patient whose frontal-sinus suppuration has subsided, or in one who has had drainage of the sinus to relieve an empyema.

4. Increasing sepsis with positive blood culture, increasing signs of meningeal irritation, and possible motor disturbances indicating thrombosis of the superior sagittal sinus.

Although these diagnostic criteria may seem vague, the diagnosis is often exceedingly difficult to make and one must depend, in many instances, upon ambiguous signs. The confusion of clinical findings which may be encountered is well exemplified in the following case report:

A female patient, A. D., No. 292537, aged 15, was admitted to the University of Michigan Hospital on August 29, 1939, complaining of frontal headache and left-sided nasal obstruction. Ten days previously she had developed severe left-sided frontal headache almost immediately after swimming and diving. Nasal discharge, left-sided nasal obstruction, fever, and bilateral supra-orbital pain and tenderness developed within three days and persisted for a week, during which time her temperature reached 104°F. on one occasion and 105°F. on another, after chills.

At the time of admission her temperature was 102°F. and the pulse was 96 per minute. There was purulent discharge filling the left middle meatus and moderate tenderness over the left frontal sinus. The leukocyte count was 17,550; the differential count of the white cells demonstrated 75 per cent of polymorphonuclear leukocytes, 21 per cent lymphocytes, and 4 per cent monocytes. Although she was too acutely ill to have an uncomplicated sinusitis, no definite evidence of extension of infection from the sinuses could be found during her two weeks of hospitalization. During the first two days a little stiffness of the neck was detected, but this disappeared within 48 hours. Radiographic examination demonstrated diffuse clouding of the left maxillary sinus and slight clouding of the left frontal sinus. The treatment was conservative and included the administration of sulfanilamide.

At the time of her discharge from the hospital on September 11, 1939, her white count was 6,900; the edema of the nasal mucous membrane and the nasal discharge had subsided completely, and there was no tenderness over the sinuses. Her temperature for three days before discharge had reached 99.6°F. in the evening but was normal during the rest of the day.

This patient was seen in the out-patient department three weeks later, at which time there was no clinical evidence of si-

nusitis. There had been a temperature elevation to 100°F. each afternoon of the preceding three days. It was stated that there had been occasional moderate frontal headache and pain in the left eye when the head was turned sharply to the left. There had been no vomiting, spells of unconsciousness, convulsive seizures, or other significant symptoms. Although the continued fever and occasional headache still suggested the possibility of an intracranial extension of infection, the findings were not definite.

Four days later she was again admitted to the hospital with a temperature of 102°F., but she had no other complaints. Clinical evidence of sinusitis had disappeared completely. The blood count revealed 5,600 white cells, of which only 29 per cent were polymorphonuclear leukocytes. There were 50 per cent lymphocytes, 10 per cent monocytes, and 11 per cent eosinophils. General medical examination was essentially negative with the exception of a palpable spleen and barely palpable cervical and axillary lymph nodes.

Because of the absence of any localizing signs or symptoms, the patient was transferred to the department of internal medicine, where such conditions as tuberculosis, undulant fever, paratyphoid and typhoid fevers, allergic reaction, and animal parasites were considered and excluded as the cause of her fever. During the succeeding two weeks the blood picture remained abnormal, the number of white cells being under 10,000 and showing on an average of only 25 per cent polymorphonuclear leukocytes and a continued very high percentage of lymphocytes and eosinophils.

On October 12, 1939 the patient began to develop a very definite localized area of tenderness high in the right frontal region, considerably above the level of the right frontal sinus, which at no time had shown evidence of infection. Radiographs of the skull demonstrated a zone of decalcification, apparently in the inner table of the right half of the vertical portion of the frontal bone, above the right frontal sinus. The clouding of the left frontal sinus had persisted since her early examination. What appeared to be a small sequestrum in the upper medial portion of the left frontal sinus was visible on the films. Neurologic findings were insignificant. Because of the persistent area of tenderness in the right frontal region and the positive x-ray findings, it was concluded that there was a beginning osteomyelitis of the inner table of the skull on the right, secondary to an epidural abscess.

Operation was performed on October 19, 1939, at which time a large and heavily encapsulated epidural abscess was discovered in the right frontal region, associated with an osteomyelitis of the inner table of the frontal bone. The patient made an uneventful recovery and her blood picture returned to normal (Figs. 47–48).

## TREATMENT
### PREVENTIVE TREATMENT

The prevention of osteomyelitis subsequent to infection in the pneumatic spaces of the skull is primarily an otorhinologic problem. Proper handling of fulminating sinus and mastoid infections, and avoidance of untimely and inordinate surgical procedures will do much toward preventing this tragic disease as a postoperative complication. When surgery is indicated it must be done with precise care. Frank suppuration continuing after a sinus or mastoid operation usually means that inadequate drainage has been established, and calls for prompt secondary operation.

There is one type of patient that has seemed especially liable to the development of postoperative osteomyelitis of the small bones of the face. This is the individual with long-standing nasal polypi of such magnitude that the nasal bones have been forced apart, producing a widening of the bridge of the nose. In such a case,

nasal polypectomy may be done with safety but an ethmoidectomy may produce dire sequelae.

In the primary treatment of skull injuries much can be done to prevent osteomyelitis. Radical removal of exposed contaminated bone at the time of operation of a compound skull fracture should be performed. A linear fracture beneath a scalp laceration is a compound fracture and a potential source of osteomyelitis, that all cases of osteomyelitis of the skull are preventable. Nearly every neurosurgeon and rhinologist of wide experience will testify that this disease may attack an individual while under the care of a master clinician. There is little doubt that many cases result from errors of omission or commission, although in individual instances these errors elude description. As in all infections the "doctrine of the prepared soil" must be considered
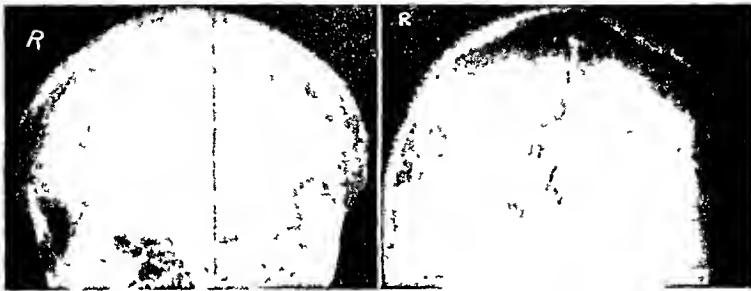


Fig. 47. Roentgenograms taken August 29, 1939, demonstrating clouding of sinuses on left side.

even though there is no visible separation of the fragments. At the moment of fracture there may have been separation of the elastic bony plates, and hair or other contaminating material may have been grasped and retained in the fracture line beneath the surface. For this reason any such exposed linear fracture should be investigated by chiseling along it with a narrow gouge to make certain that there is no imbedded foreign material.

Chemotherapeutic agents, such as the sulfonamides and penicillin, have accomplished much in the treatment of fulminating sinusitis and without doubt have prevented many severe complications. Likewise, there is substantial evidence to show that the administration of these agents tends to stop or greatly retard the spread of an established osteomyelitic focus (see Chapter 19).

These statements carry no implication

## CURATIVE TREATMENT

The treatment of osteomyelitis of the skull is surgical. Whether the process is fulminating and spreading, or apparently localized, the demand for complete excision of the focus is uncompromising. One cannot depend upon continued localization of the focus and thus hope for cures by timid surgical procedures. In regard to specific types of operations it must be emphasized that every case should be individualized and considered upon its own merits.

As curative therapeutic agents the sulfonamide drugs have been disappointing, although there have been a few cures reported. Penicillin is generally more effective and may produce a cure of this disease if it is administered at the onset of the infection. Clinical experience has demonstrated, however, that chemotherapy can not be substituted for surgery in a well-

established case of osteomyelitis of the skull.

Every patient should be prepared adequately for operation by blood typing and cross matching with donors, since trans-

The operative technic varies considerably among surgeons of experience. The incision should serve to expose the field, to preserve the blood supply of skin flaps, and to produce minimal deformity after
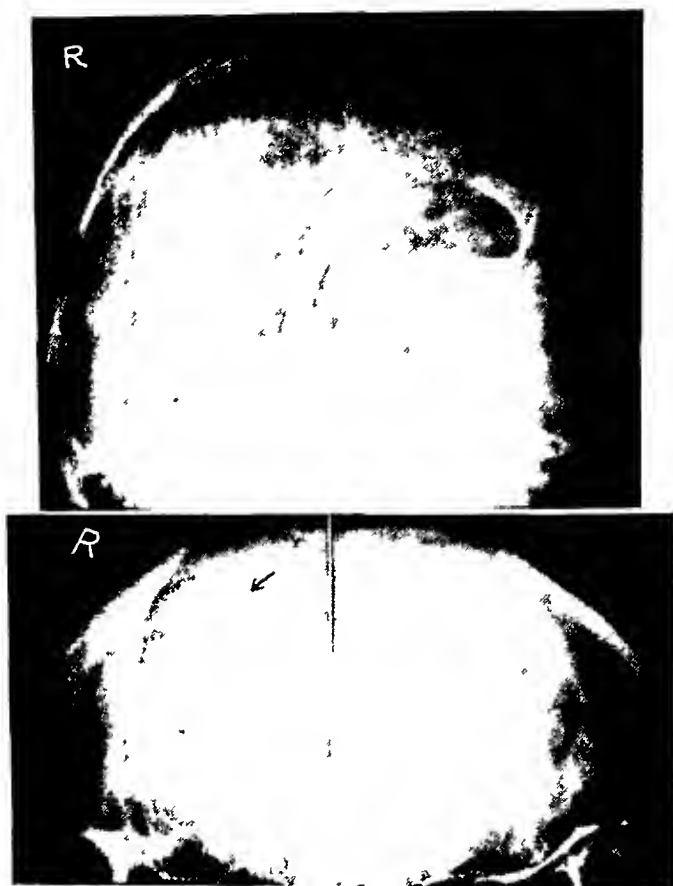


Fig. 48. Roentgenograms taken October 13, 1939. In postero-anterior projection note small sequestrum in region of upper limits of intersinal septum. Left frontal sinus is still clouded. In the oblique projection the large area of rarefaction in right frontal bone is well demonstrated.

fusions of 500 to 1,500 cc. of blood are usually necessary during the operation.

General anesthesia is used extensively, and the intratracheal administration has many advantages in cases requiring ethmoidectomy with the concomitant bleeding into the throat.

meeting the first two requisites. Various types of incisions employed to expose areas of osteomyelitis of the frontal bone are depicted in Figs. 49–54.

In cases of frontal osteomyelitis, the coronal incision (Fig. 49) has many advantages. In the first place, the reflection

of the forehead flap gives complete exposure of the frontal bone, including the important zygomatic processes, and also allows access to the temporal fossae. An additional sagittal incision, as indicated in Fig. 50, permits exposure of the parietal bones. Exposure of the frontal bone by the coronal incision allows the surgeon to excavate any diseased tissue in the anterior ethmoid group of cells; and, if the frontal sinus is deep, a complete ethmoid and sphenoid operation can be accomplished

for definite unilateral disease, the lateral L-shaped or a flap incision (Figs. 53–54) serves the purpose well.

There is some doubt regarding the advantages of the wide-open packing of the wound except in cases of proved anaerobic infection. If clean bone is left exposed by the open packing method, it may suffer the ravages of secondary osteomyelitis.

After exposure of the field, both tables of the frontal sinus on one or both sides must be removed. If the signs and symp-
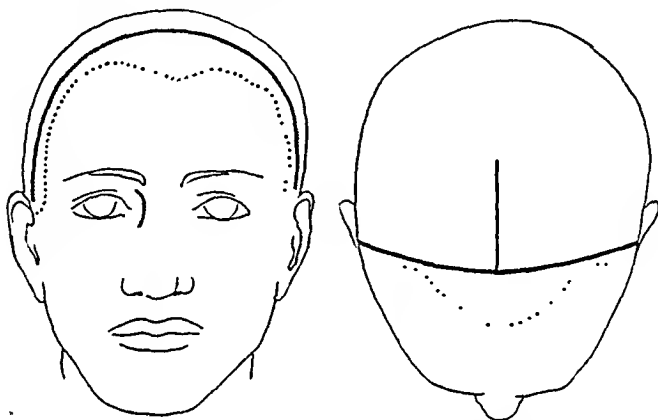


FIG. 49. (*Left*) Coronal incision within hairline and additional incision on side of nose to facilitate exposure of ethmoid and sphenoid sinuses.
FIG. 50. (*Right*) Coronal incision with supplemental sagittal incision permitting exposure of parietal regions.

even while leaving the supra-orbital ridge intact. In many cases it is necessary to make an additional short curvilinear incision at the side of the nose (Fig. 49) in order to gain complete exposure of the ethmoidal labyrinth and the sphenoid sinus. This latter procedure may be performed at the time of the first operation if the patient's condition permits, or at a later date if indicated. Secondly, the blood supply of the flap is adequate. Finally, deformity is minimized by the type of closure to be described subsequently (Fig. 51). If one deems it necessary to pack the wound wide open, the inverted T incision (Fig. 52) or,

toms of osteomyelitis have been present, this procedure must be done even though the posterior table appears to be intact. One should assume that an epidural abscess is present. If the osteomyelitic focus appears to be localized and seems to involve only the anterior table of the skull, the dura should be exposed if this superficial osteomyelitic area is beyond the limits of the frontal sinus. No harm will come from exposing the dura if it is done carefully to avoid tearing.

Removal of bone may be accomplished piecemeal, by the use of the rongeur, or by block resection. The latter method has

the very questionable advantage of permitting the surgeon to work in uninfected bone, providing the extent of the diseased bone and dura permits of a precise preoperative determination. This advantage is more readily apparent in a case of traumatic osteomyelitis than in one associated with an empyema of one or both frontal sinuses The disadvantages lie first in the



FIG. 51. Photograph of a patient taken four weeks after operation for osteomyelitis of left frontal bone.

difficulty of predetermining the exact amount of bone to be removed, and second in the added danger of perforating the dura or the sagittal sinus, which may be unusually adherent to the inner table due to inflammatory reaction. The piecemeal removal by rongeur is safe providing a dural elevator is used to separate the dura from the inner table in advance of the rongeur. Also, this latter method has the advantage of allowing the surgeon to follow the infected bone in any direction or

to any required extent. If the patient's condition should be poor, this technic lends itself more readily to a two-stage procedure.

When does one stop removing bone? There is no definite answer to this question but there are certain criteria which define the termination of the operation. Bone should be removed until healthy bone, from the standpoint of gross appearance and feel, has been reached; and then removal of bone should be continued until there is about an inch of healthy-appearing dura exposed beyond the grossly infected bone. The latter recommendation is made because an epidural abscess, produced by the spread of infection along the surface of the dura, may be encountered at some distance beyond the edge of grossly infected bone, and beyond the area of scalp edema. One must not hestiate to follow the diseased bone and dura well beyond the apparent limits of suppuration, even if this should necessitate the removal of the entire calvarium, and include the rim of the foramen magnum. The surgery does not have to be done in one stage if the patient's condition will not permit.

If, after an industrious and apparently successful attempt to remove all of the osteomyelitic bone, the wound continues to suppurate for a week or more, or if signs of extending infection become obvious before that time, a secondary operation must be done at once. Such an unfortunate occurrence need not demand self-incrimination on the part of the surgeon. The operation must terminate at some point, and if the removal of bone has gone to the extent previously described, further extension of the disease does not discredit the surgeon's work.

The problem of drainage and wound closure is open to much debate. Surgical practice employs procedures varying from maintenance of wide-open drainage until complete filling with granulations has oc-

curred, to tight closure after packing the wound with sulfanilamide powder. The decision regarding the disposition of the wound should rest upon the type and extent of the disease, the apparent necessity for continued observation of the operative site, and the opportunity for adequate drainage plete eradication of the osteomyelitic focus has been accomplished. If wide-open drainage into the nose has been provided by the removal of the floor of the frontal sinus, the ethmoid cells, and the middle turbinate, the coronal incision may be closed except at its lateral extremities. A gauze pack
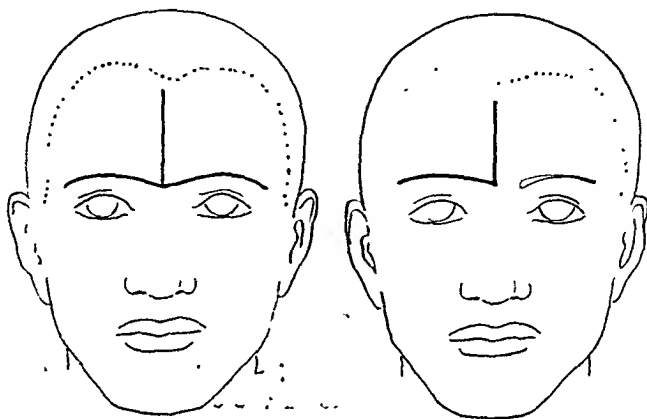


FIG. 52. (*Left*) Inverted T incision which may be used to expose frontal bone and both frontal sinuses.
FIG. 53. (*Right*) Angular incision to expose one frontal sinus and adjacent frontal bone.
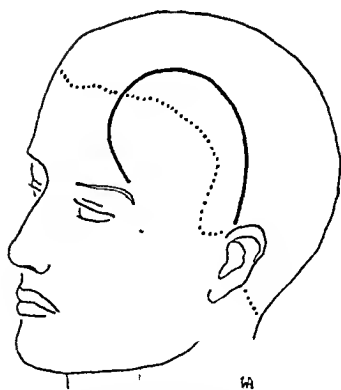


FIG. 54. Outline of flap to expose localized focus of osteomyelitis in frontal bone.

through the nose, in cases of frontal bone osteomyelitis.

Partial closure of the wound has not produced deleterious results, providing com-

soaked in 1:1,000 metaphen-in-oil should be placed over the infected dura and brought out the lateral end of the coronal incision. The same type of pack may be employed if there has been an accidental perforation of the dura. In the event that no dural infection is found and the dura is preserved intact, a Penrose type of rubber-tube drain may be used to secure drainage from the lateral extremities of the incision. The insertion of a rubber catheter into the wound will allow the frequent instillation of penicillin. A petrolatum gauze pack may be placed in each frontal sinus and one end pushed downward into the nose. This pack serves chiefly a hemostatic function and should be removed after 24 hours.

If the osteomyelitis is in the frontal bone and associated with an empyema of the frontal sinus, and if wide drainage into the

FIG. 55. Photographs of patient before and after implantation of acrylic resin mold to correct deformity produced by operation for osteomyelitis of frontal bone.



FIG 56. X-rays showing amount of bone removed from patient whose photographs appear in Fig. 55.

nose is not secured, the wound should be left open.

If the infection in the calvarium is well separated from the pneumatic spaces of the skull, and is not the result of a direct extension from these cavities, the wound may be partially closed and drained by means of rubber tubing if the dura is free from gross inflammatory change. A piece of gauze soaked in metaphen-in-oil may be used for drainage in cases of dural injury or an epidural abscess. Four-ply gauze, two inches wide, serves well in this capacity.

## POSTOPERATIVE CARE

Replacement of blood loss, administration of fluids, chemotherapy, and constant alert vigilance to detect any evidence of further extension of infection are the paramount postoperative procedures.

Blood loss during the operation is usually significant, and the transfusion of 500 to 1,500 cc. of blood during the operation may need to be supplemented postoperatively. A careful check on the erythrocyte count and hemoglobin content should be kept.

Until the patient is able to take adequate fluids by mouth, 5 per cent glucose should be given intravenously by the continuous-drip method. Physiologic saline is indicated when there has been loss of chlorides.

Penicillin, or sulfadiazine, and in many cases both of these agents together, should be administered in adequate doses after the surgical operation.

The wound should be inspected and dressed daily to detect evidence of possible extension of the osteomyelitic process. Daily blood counts are of great assistance in determining the presence of a secondary focus. Evidence of continued frank suppuration after a week demands surgical exploration.

Rubber drainage tubes may be removed after from four to seven days. The metaphen-in-oil gauze pack should be left in place for ten days, then removed under brief anesthesia, such as may be obtained by the intravenous use of pentothal sodium. Since blood clots may interfere with drainage into the nose and allow accumulation of secretion in the frontal sinuses, it is advisable to insert a suction cannula through the nose into these sinuses at the end of the first postoperative week or ten days. It may be necessary to repeat this procedure on two or three occasions at intervals of five to seven days.

## REPAIR OF DEFORMITY

Wounds that have been left open may be closed and repaired by plastic procedures after all infection has subsided. In plastic closure the defect may be filled by autochthonous bone or cartilage implants, preserved cartilage, either diced or in strips, or by a mold of one of the acrylic resins, or preferably tantalum. Figs. 55 and 56 demonstrate one case in which the deformity was alleviated by implanting an acrylic-resin mold.

In some instances bone regeneration serves to reduce or even correct the deformity.

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# CRANIAL AND INTRACRANIAL SURGERY

## TUMORS

# 7

# Tumors of Skull

## Cobb Pilcher, M.D.

True neoplasms arising in the skull must be distinguished from two other groups of bony abnormalities. These are the hyperostoses and the destructive lesions whose nature is poorly understood, such as Paget's disease and Schüller-Christian's disease. These conditions may be mentioned here briefly only in order to facilitate such a distinction.

### HYPEROSTOSES

Hyperostoses, or simple bony overgrowths, may occur in either the inner or outer table of the skull. They may be spontaneous in their origin and lifelong in duration, or they may arise through the stimulation of an underlying meningeal tumor.* The former type occurs most frequently in the inner table of the frontal bones. It is symmetrical and irregular in its inner contour and may reach a thickness of 1.0 to 1.5 cm. This *hyperostosis frontalis interna* (Moore[14]) is usually associated with mental and personality abnormalities and sometimes with psychoses. It is much more frequently seen in women than in men.

### PAGET'S DISEASE (OSTEITIS DEFORMANS)

Paget's disease (osteitis deformans) is a systemic disorder of bone which nearly always involves one or more long bones and the skull. It is characterized by bone destruction, accompanied and followed by overcompensating repair, so that, in the skull, the picture is one of irregularly "cottony" bone of much greater than normal thickness. There is no effective treatment.

### SCHULLER-CHRISTIAN'S DISEASE

Schüller-Christian's disease is also a general disorder, in which the skull shows irregular punched-out areas. Microscopically these lesions vary, but commonly they are xanthomatous. Similar lesions with collections of xanthomatous material are frequently found in the infundibular region and may be accompanied by neighborhood symptoms, such as diabetes insipidus and optic atrophy. The disease commonly makes it appearance in childhood.

### EOSINOPHILIC GRANULOMA OF BONE

Eosinophilic granuloma of bone is a somewhat similar lesion characterized by solitary or multiple destructive lesions of the skull or other bones. First described by Otain and Ehrlich[10] and Lichtenstein and Jaffe,[12] the lesions are granulomas, containing large numbers of eosinophils. There is an excellent response to radiation therapy (Osborne, Freis and Levin[15]).

* Cf. Chapter 8, Tumors of Meninges.

## OSTEOFIBROMA

Osteofibroma, a condition somewhat similar to osteitis fibrosa cystica in long bones occurs rarely in the skull (Eden,[5] Schwartz[20]).

## OSTEOMAS

True osteomas of the skull are of two types: (1) Those arising in the paranasal air sinuses (especially the frontal and ethmoid sinuses), and (2) those arising in the cortical layers of the skull itself.

**Osteomas of Sinuses.** These are usually, but not always, unattached to the sinus walls. Indeed, they have sometimes been called "stones," but since they are composed of true bone they should properly be considered to be osteomas. Their growth is extremely slow and results in gradual expansion of the sinus, sometimes to enormous proportions. Ultimately the sinus walls are penetrated and the tumor comes to protrude into the orbit or the intracranial chamber or both (Fig. 57, B). The protruding portion may then become quite large, remaining connected with the original tumor by a narrow "neck" which is enclosed closely by a "collar" composed of the thin bone of the sinus wall or orbital roof.

The tumor is almost invariably nodular (Fig. 57, A, B, C) and the mucous membrane of the sinus becomes tangled about the nodules, with the production of numerous small mucoceles. The appearance is often that of a bunch of grapes. Communication with the nasal cavity may result in infection either before or after operation, and this constitutes a grave danger attendant upon the surgical removal of the tumor. Cerebrospinal-fluid rhinorrhea and intracranial pneumatocele are not infrequent complications (Kessel[10]).

On gross section the lesion shows a cortical covering of hard dense bone and a central core of spongy cancellous bone. Microscopically the tumor has the appearance of normal bone.

When the tumor is still within the sinus, the only symptom is likely to be headache due to expansile pressure. If the lesion breaks into the orbit, the globe is compressed, there is gradual failure of vision, progressive proptosis takes place (Fig. 57, D), and the eye may ultimately be destroyed. Infection may result in the development of orbital cellulitis. In three remarkable cases reported by Lucas,[13] Hilton,[9] and Bland-Sutton,[3] respectively, the tumor fell out through the orbit spontaneously, after destroying the eye.

If the tumor extends into the cranial cavity, the dura may be pushed before it, but is more likely gradually to be eroded, with resultant protrusion of the tumor into a "nest" in the frontal lobe. Since the lesion is far forward, focal neurologic symptoms rarely occur. However, infection may result in meningitis or brain abscess or both (Pilcher[17]).

The diagnosis is readily proved by roentgenographic studies (Fig. 57, B).

When the tumor is very small and lies entirely within the intact sinus, the usual external approach employed by rhinologists may be quite adequate. On the other hand, once the sinus wall is ruptured, whether into the cranial cavity or the orbit, an intracranial approach should be used in *all* cases. This fact was emphasized by Cushing[4] in 1927, in a report of the first two cases so treated, and later by Pilcher[17] and by Bagdasar, Schmitzer, and Bagdasar.[1] Only from within the skull can the surgeon gain adequate exposure, avoid irreparable damage to brain and eye, control intracranial hemorrhage, repair dural defects, and, incidentally, obtain the most satisfactory cosmetic result in most instances. The operation is a formidable one and should not be undertaken by a surgeon without neurosurgical experience.

OPERATIVE TREATMENT. A frontal bone
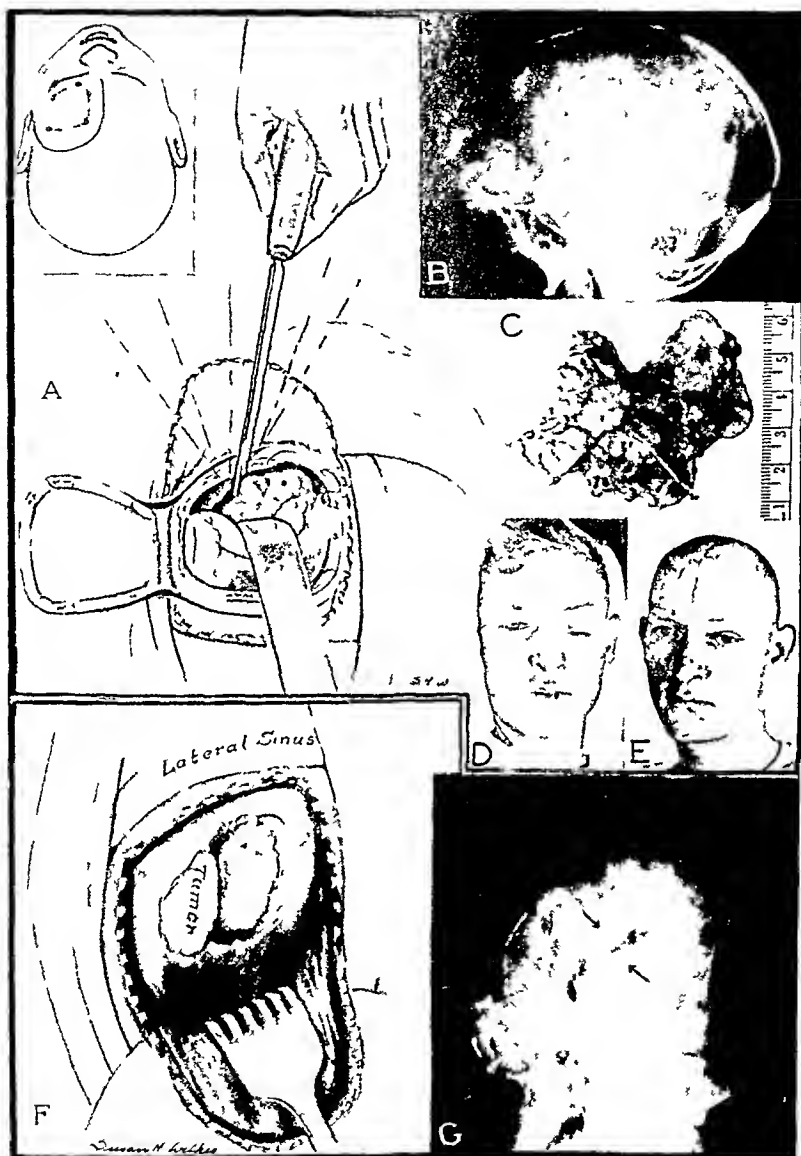
FIG. 57. Osteoma and epidermoid. (A) Removal of osteoma of frontal sinus with orbital and intracranial extensions. Orbital roof and sinus wall have been chipped away from tumor and dura has been opened. Mass is being gently "rocked" from its bed. (B) Lateral roentgenogram and (C) actual photograph of same tumor. (D) Photograph of patient before operation. Note swollen eyelid over proptosed eye and protrusion of forehead over inner border of left eye. (E) Photograph of patient after operation. (F) Epidermoid of occipital bone. (G) Roentgenogram (oblique) of same tumor, showing clean-cut bony defect adjacent to mastoid.

flap is turned down with its anteromedial border as far forward as possible without entering the frontal sinus (cf. Chapter 1). The approach is the same for tumors of both ethmoid and frontal sinuses, but a greatly expanded frontal sinus may alter the position of the flap (Fig. 57, A, inset).

The frontal lobe is gently elevated extra-durally until the "neck" of the intracranial portion of the tumor is encountered. Here it is necessary to incise the dura on top of and lateral to the tumor. This, with further elevation, allows the brain to slip off the surface of the bony mass and be retracted. This dissection is aided by brushing away the brain with moist cotton pledgets. Portions of the grapelike mucocele may be left behind in the cavity occupied by the tumor and should be searched for and removed.

The narrow collar of thin bone through which the tumor communicates with the sinus is then chipped away, first with a small chisel and subsequently with pointed rongeurs, until adequate space to deliver the lesion from the sinus is obtained. In exactly the same way the orbital roof is removed to whatever extent may be necessary. The tumor will then sometimes almost fall out Usually, however, its nodular structure causes it to be held fairly firmly in position. A narrow osteotome should be inserted under it and the tumor gently "rocked" from its position until it is completely free (Fig 57, A).

In some instances the tumor will be found to arise from and have a broad base of attachment in the wall of the sinus. In such cases it is far better to cut off the mass flush with the floor of the sinus than to attempt a traumatizing and mutilating radical removal of the base of attachment.

The mucosa of the sinus must be completely curetted away. The dural defect should be repaired with a periosteal or fascial graft or with fibrin film. If there is evidence of infection a tube should be inserted into the sinus through the nose (in

the case of the frontal sinus). Otherwise a small stab drain inserted through a frontal burr hole is adequate. A small amount of sulfanilamide may be dusted into the wound.
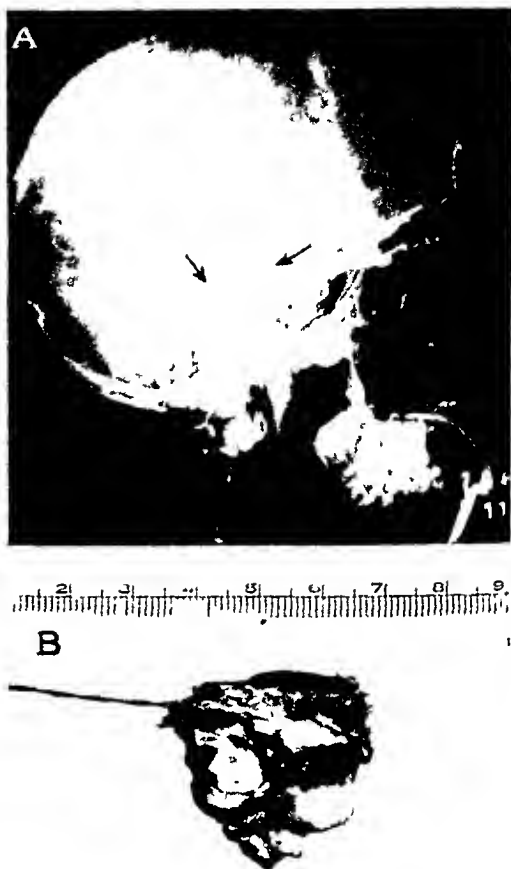


Fig. 58. (A) Roentgenogram of osteoma of inner table of temporal bone. (B) Photograph of same tumor after removal.

Osteomas of Calvarium. These may arise from either inner or outer table, but the latter origin is more common (Geschickter[7]). Such tumors rarely attain great size, but occasionally they may seriously compress the brain, resulting in pressure symptoms and sometimes in epilepsy (Pilcher[17]). When small they push the dura ahead of them, but the larger le-

sions usually erode the dura, which becomes adherent to the margins of the tumor and gives the impression of having been penetrated by direct invasion (Fig. 58, A, B).

The osteomas arising from the external table of the skull frequently follow trauma.

OPERATIVE TREATMENT. This should consist, whenever possible, of block removal. This may be accomplished, with the smaller lesions, by making a single nearby burr hole, and encircling the tumor with an undercutting forceps of Montenovezi type. Larger tumors require multiple burr holes connected with the Gigli saw.

If the tumor protrudes deeply into the brain and is firmly attached to the dura, it is wise to reflect a small adjacent bone flap. Only in this way may adequate exposure be obtained to permit safe division of the dura about the neck of the tumor, to avoid serious cerebral damage, and to control hemorrhage if it occurs.

Dural defects should be meticulously repaired with fascial transplants or fibrin film.

## HEMANGIOMAS

Hemangiomas are in reality congenital vascular anomalies, but they may assume neoplastic proportions through gradual enlargement and increased tortuosity of the vessels with resultant production of local pressure. In the skull they vary from small solitary lesions which remain stationary in size indefinitely to huge or multiple masses which may communicate with extensive masses of vessels in the scalp or on the surface of the brain (Schwartz[21]).

The individual lesions have a characteristic roentgenographic appearance. There is a rather sharply outlined area of increased penetration in which may be seen a *linear* trabeculation. The lesion grows very slowly and gradually expands both inner and outer tables, both of which it may ultimately rupture. Thus there may be a palpable ex-

ternal bony mass and, in tangential roentgenograms, the inner table may show either a smooth in-bending or a rupture of its continuity with adjacent irregular intracranial calcification (Fig. 59, A).



FIG. 59. (A) Hemangioma of frontal bone. Lesion has ruptured through the inner table and produced a calcified intracranial mass. (B) Metastatic carcinoma of skull.

Small hemangiomas commonly cause no symptoms and may be discovered by accident. Even so, they should be observed carefully for evidences of growth. When the calvarium is expanded and particularly when the inner table is penetrated, severe

headaches and sometimes focal cerebral symptoms may appear. A bruit is rarely present.

Multiple or very large hemangiomas of the skull or those associated with extensive intracranial angiomatosis should rarely be operated upon. Deep x-ray therapy may retard the growth or even diminish the size of these lesions. Only the solitary hemangiomas which are producing symptoms are satisfactory subjects for operation.

Operative Treatment. As with the osteomas, operative treatment consists in block removal. The surgeon must be prepared to deal with sudden severe hemorrhage from unexpected intracranial vascular connections and should never neglect to provide adequate exposure.

## METASTATIC TUMORS
## OF SKULL

Metastatic tumors of the skull may be secondary to any malignant tumor elsewhere, but carcinoma is the most common type and the breast the most frequent primary site. Such metastases must be blood-borne and earlier pulmonary metastases are usually present.

Metastases in the skull may apparently be solitary but are usually multiple. In roentgenograms there may be irregular areas of complete destruction, but the picture is usually that of a peculiar granular, "moth-eaten" bone whose outlines are not perfectly demarkated (Fig. 59, B). They cause symptoms only as a result of extension inward to involve the brain or outward to produce a mass in the scalp. Such extracranial masses frequently result in extensive ulceration.

If the diagnosis is definite, metastatic tumors of the skull should rarely, if ever, be subjected to operation.

## EPIDERMOIDS

Epidermoids, sometimes loosely called "cholesteatomas," occasionally arise in the diploe of the skull. These lesions are congenital and are really cysts, lined with squamous epithelium and entirely filled with flaky white epithelial débris. They enlarge extremely slowly and gradually expand and thin the cortical layers of the skull. In roentgenograms (Fig. 57, G) they present a smoothly outlined, usually oval area of increased penetration, with or without demonstrable local expansion of the skull in tangential views (Rowbotham,[10] King[11]).

The tumors should not be confused with the so-called cholesteatomas of the middle ear. They may occur in the bone adjacent to the mastoid (as well as intracranially adjacent to the pons), but they are entirely distinct from the aural collections of cellular débris.

Operative Treatment. Operative treatment is indicated in all accessible cases. The procedure will vary with the size and location of the lesion. Small tumors, favorably situated, may be completely removed by block excision. In other instances, in which the tumor has eroded its way to relative freedom from tight bony connections, enucleation of the cyst capsule, en masse, is possible (Fig. 57, F). Frequently, however, it is necessary to open the capsule, remove the contents with a pituitary spoon, and then carefully curette away every particle of the lining membrane.

## OTHER TUMORS OF SKULL

Benign giant-cell tumors of the skull have been reported rarely. They may be attacked surgically and should be subsequently irradiated. Arteriovenous aneurysms sometimes extend completely through the skull with formidable vascular lesions in the scalp and in the cranial chamber. Primary carcinomas of the scalp frequently invade the skull.

## REPAIR OF SKULL DEFECTS

Contrary to popular belief, even a rela-

tively large defect in the skull does not in itself constitute a serious danger to the life or health of the patient. The risk of injury is restricted to the danger of direct penetration of the defect by some sharp instrument—a very unlikely eventuality. True, epilepsy frequently results from the cortical scars which may underlie such defects, but these cortical changes are irreversible and will not be altered by repair of the bony defect.

However, if very large openings exist, there is danger of injury and repair of such defects should be carried out. In addition, openings in the frontal bones may demand repair for cosmetic reasons or because the visible and palpable pulsation of the underlying brain constitutes a psychologic handicap to the patient.

Progressive improvements in substances employed for repair of defects in the skull have succeeded each other rapidly in recent years and it is not yet possible to state that an ideal method has been attained. For this reason, the technic of various methods will not be discussed in this chapter, but brief reference will be made to those methods which have been most satisfactory or which offer the most promise.

Silver plates have long since been abandoned. Osteoplastic flaps of the outer table of the skull and cartilage transplants still have some usefulness (Grant and Narcross[8]). Plates of celluloid and of vitallium have been used extensively but have their own disadvantages (Venable and Stuck,[23] Beck[2]). Recently, two additional substances have given great promise. These are tantalum (Pudenz,[18] Fulcher[6]), an inert and malleable metal, and lucite (Shelden, et al.[22]), a plastic material which is readily cast into any desired shape and size. (Cf. Chapter 4.)

Following are the important factors which must be borne in mind in repairing defects in the skull:

1. No such repair should be attempted

at the site of a previously infected wound until a long period of complete freedom from evidences of infection has elapsed.

2. Underlying dural defects should, if possible, be repaired separately with fascial transplant or fibrin film. In large defects it is important to have the brain expanded to a normal contour, if possible.

3. The substance chosen to fill the bony defect should be nonirritating and should not produce electrolytic activity in tissue. Tantalum and lucite are preferable at the present writing.

4. The "plate" should fit accurately, should simulate the normal contour of the skull, and should be fastened firmly to the surrounding skull with as little thickness of the overlapping edges as possible.

5. If the dura has been satisfactorily closed, small openings in the "plate" are permissible and even desirable.

6. Complete closure of the wound with healthy scalp must be attained. Shifting of scalp flaps or relaxation incisions may be necessary for this purpose.

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# 8

# Tumors of Meninges

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With a few exceptions, which will be discussed later in this chapter, the neoplasms arising from or involving the meninges are meningiomas. It is to this great and rather complex group of tumors that the greater part of this chapter will be devoted.

### THE MENINGIOMAS

The term "meningioma" was introduced by Cushing[4] in 1922. The name has received widespread acceptance, perhaps because, as Cushing intended, it makes unnecessary a choice among numerous terms ("dural endothelioma," "tumeurs fongueuses da la dure-mère," "tumeurs cancéreuses de le dure-mère," "Sarkome der Dura mater") based on controversial pathologic evidence.

The splendid monograph entitled Meningiomas by Cushing and Eisenhardt[5] included a detailed presentation of 295 intracranial meningiomas and should be consulted regarding all controversial subjects related to the etiology and histologic nature of these tumors, and also for a very extensive bibliography.

### SURGICAL PATHOLOGY

Although the evidence is not complete, it is now generally believed that the meningiomas have their origin from cell clusters in the arachnoidal villi. As would be expected from this hypothesis, they may occur anywhere in the distribution of the leptomeninges, but they are most common at those sites in which the arachnoidal villi are most numerous. Thus they occur most frequently over the convexities of the cerebral hemispheres (particularly in the parasagittal area), next most frequently along the sphenoid ridges, somewhat less commonly in the olfactory groove, suprasellar region and posterior fossa, and rarely in various other scattered locations. One such unusual but interesting site is the lateral ventricular cavity. These tumors arise from the tela choroidea and usually lie free in the ventricle except for their vascular attachment to the point of origin.

In spite of a wide variation in histologic nature, rapidity of growth, size, and location, a number of gross pathologic characteristics are common to the great majority of the meningiomas.

They are usually encapsulated except for the site of their meningeal attachment (Figs. 60, 62, 63). They may create by pressure enormous excavations in the cerebral hemispheres, but the pia mater almost always remains intact and the brain is rarely invaded.

They invade the adjacent dura and frequently the bone as well (Figs. 62–63). This is of great surgical significance for the involved dura and bone must be completely removed if the tumor is to be entirely eradicated.

They produce other changes in bone. These are variable. The most common al-

teration is hyperostosis (Fig. 61) which may vary from minimal thickening of the inner table to an enormous bony mass in the calvarium. Pressure erosion of the skull may occur. Combinations of erosion, invasion, and hyperostosis may produce vary-

They are extremely vascular. The tumors themselves have an extensive arterial supply from their dural attachments and from bridging pial arteries. Their venous drainage is largely through the dura, or into the great dural venous sinuses. The

FIG. 60 Gross appearance of meningiomas. (A) Two meningiomas which lay very close to each other in right parietal lobe of a single individual. Large tumor weighed 123 Gm. and small one 15.5 Gm. Note dura still attached to each tumor. (B) Involved bone and dura removed in case of small meningioma of convexity. (C) A tiny, 2-Gm. meningioma which lifted from its cortical bed when dural flap was reflected. Two Jacksonian seizures had been patient's only symptoms. (D) Intraventricular tumor, showing artery and vein which constituted its sole attachment.

ing changes which have been well described by Phemister[14] and by Cushing and Eisenhardt.[5] In all cases the vascularity of the bone is greatly increased (see below).

parasagittal meningiomas are likely to be attached to the wall of the superior longitudinal sinus and sometimes invade its lumen, even to the point of occlusion.

The vascularity is not confined to the tumor itself. The vessels of the scalp and of the skull are increased in size and perhaps in number. Great distended and tortuous veins may frequently be seen in the shaven scalp and roentgenograms will often show of the olfactory groove which may be very large before any symptoms appear at all. The largest meningioma seen by the author weighed 381 Gm.[15]

Many meningiomas are smooth and globular (Figs. 63–64). Others, especially in



FIG. 61. Roentgenographic demonstration of meningiomas. (A) and (B) Hyperostosis of outer sphenoid and orbital roof with exophthalmos produced by pterional meningioma. (C) Rosette of diploic vessels with central hyperostosis pointing to underlying tumor. (D) Calcification of a small meningioma.

numerous distended diploic vascular channels in the skull (Fig. 61). The latter sometimes form a "rosette" centering over the lesion.

The variable factors in the gross pathology of meningiomas are numerous. Tiny nodules may be incidental findings at necropsy in contrast to the enormous tumors the outer sphenoid region, occur as flat plaques covering an extensive area of the cortex. Occasionally the lesions have an irregular nodular or lobulated surface. The majority are firm, reddish-purple, with large capsular vessels and an unmistakable appearance. The cut surface is usually of a coarse granular appearance. However, the

more rapidly growing, cellular tumors may be soft, semifluctuant, and gelatinous on the cut surface. Cysts, containing slightly viscid, dark yellow fluid with a high protein content, are occasionally encountered. Gross calcification with a "gritty" cut surface occurs in some meningiomas.

The microscopic pathology of meningiomas is another extremely variable factor. Bailey and Bucy[3] divided them into nine types. Cushing and Eisenhardt[6] also described nine classes under a somewhat different terminology. Despite this wide variability the majority of meningiomas fall into three general categories:

1. Most common is the "meningothelial" ("endothelial") type in which the cells are uniform, round, or polyhedral, and distributed in smooth sheets or lobular bundles. Mitoses are rare, vascularity is moderate. Neither collagen nor reticulin is elaborated by this group.

2. The "psammomatous" or "whorl-pattern" meningiomas have a concentric arrangement, sometimes interspersed with parallel streams of cells. The whorls may have central granules of calcification (psammoma bodies).

3. The purely fibroblastic meningomas constitutes a large group. They are often subdivided and vary from slowly growing benign lesions composed of streams or sheets of uniform elliptical fibroblasts to malignant "sarcomatous" types in which the cells vary in size and shape and in which all the evidences of rapid growth can be seen.

In addition to these three common groups, rarer meningiomas have been described as "angioblastic," "chondroblastic," "osteoplastic," and "lipoblastic."

The tendency of many meningiomas to recur (or rather to continue to grow) after apparently complete surgical removal is well known. The time of recurrence of symptoms varies greatly, however, from rare cases recurring within months or a few

years to the more common recurrence after many years. It is striking that the histologic type rarely varies from that originally found. The rate of growth can usually be predicted with fair accuracy by a knowledge of the original history and a study of the microscopic nature of the tumor.

## DIAGNOSIS

Essentially, the symptoms and signs produced by meningiomas are those associated with other intracranial neoplasms, varying with the rapidity of growth and location of the lesion. Since the majority of meningiomas grow slowly, the clinical picture is likely to be insidious in onset, slow in development, and long in duration. In some cases, symptoms have been present for many years before neurosurgical advice is sought.*

Meningiomas are tumors of middle life. *The great majority present themselves for treatment between the ages of 35 and 55.* They are somewhat more common in women, particularly in certain locations.† The relationship of trauma to the development of meningiomas, though supported by many authors, is not clearly established.

In many instances the focal neurologic signs produced by a meningioma do not differ significantly from those of other tumors. Sometimes, however, the favorite sites of the meningiomas are associated with such characteristic symptoms that the latter become presumptive evidence favoring a correct pathologic diagnosis. Jacksonian convulsions are quite commonly associated with the tumors of the parasagittal region and other portions of the hemisphere convexity. Bitemporal hemianopia and optic atrophy without hy-

* The author recently removed a meningioma from a patient who had had occasional focal cortical irritative seizures for 23 years, and two of Cushing's patients had 30-year histories.

† The pterional and the intraventricular meningiomas have been observed almost exclusively in women.

tutes a critical period in operations for meningiomas, for profuse hemorrhage may occur from bone and dura before adequate exposure permits the use of suitable hemostatic methods. The flap should be turned as rapidly as possible without unnecessary trauma.

At this stage there will be free venous bleeding from the external surface of the area of dural involvement (when dealing
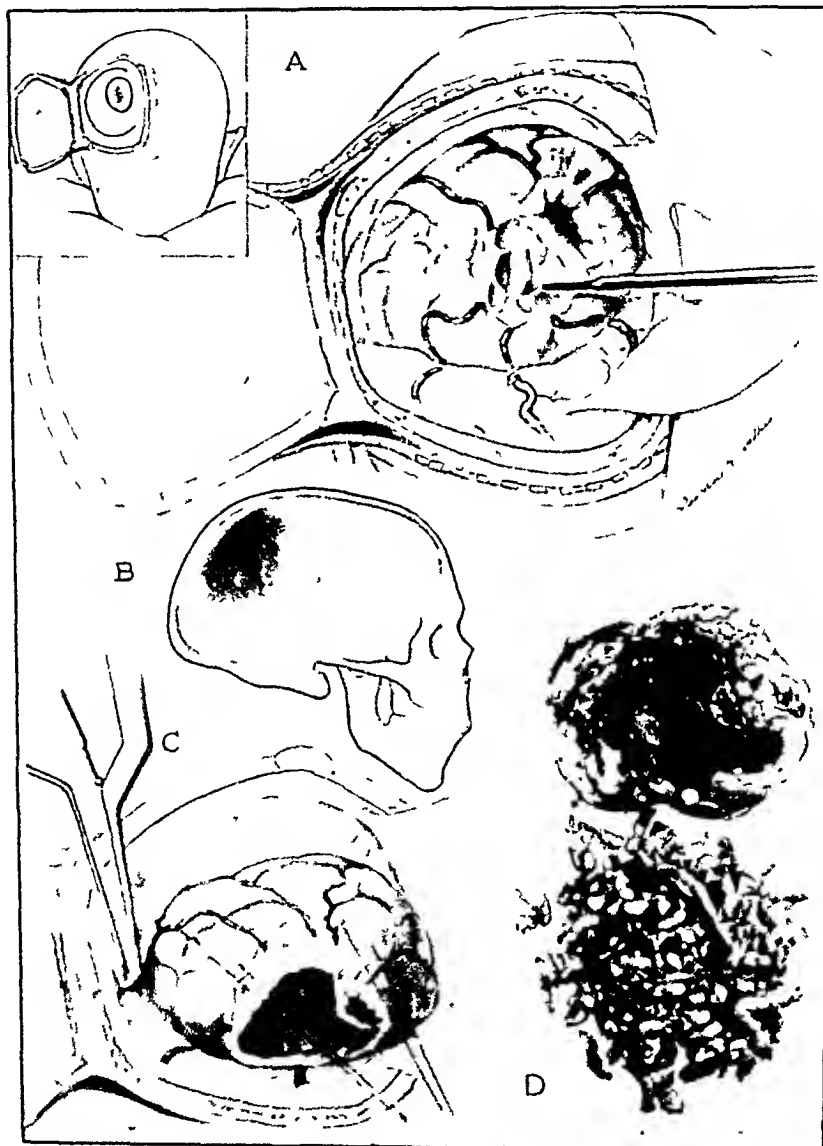


Fig. 62. Removal of large parieto-occipital meningioma of convexity. (A) Excavation of tumor with electric loop. Note that involved dura has been left attached. (B) Ventricular distortion produced by tumor. (C) Delivery of excavated tumor after division of bridging vessels. (D) Photograph of tumor, with worm-like "scallopings" from its interior.

with parasagittal or convexity meningiomas). This may be controlled by a sheet of warm, moist cotton or may require the application of muscle or fibrin foam.

After coagulation of the dural arteries the dural flap should be reflected with its
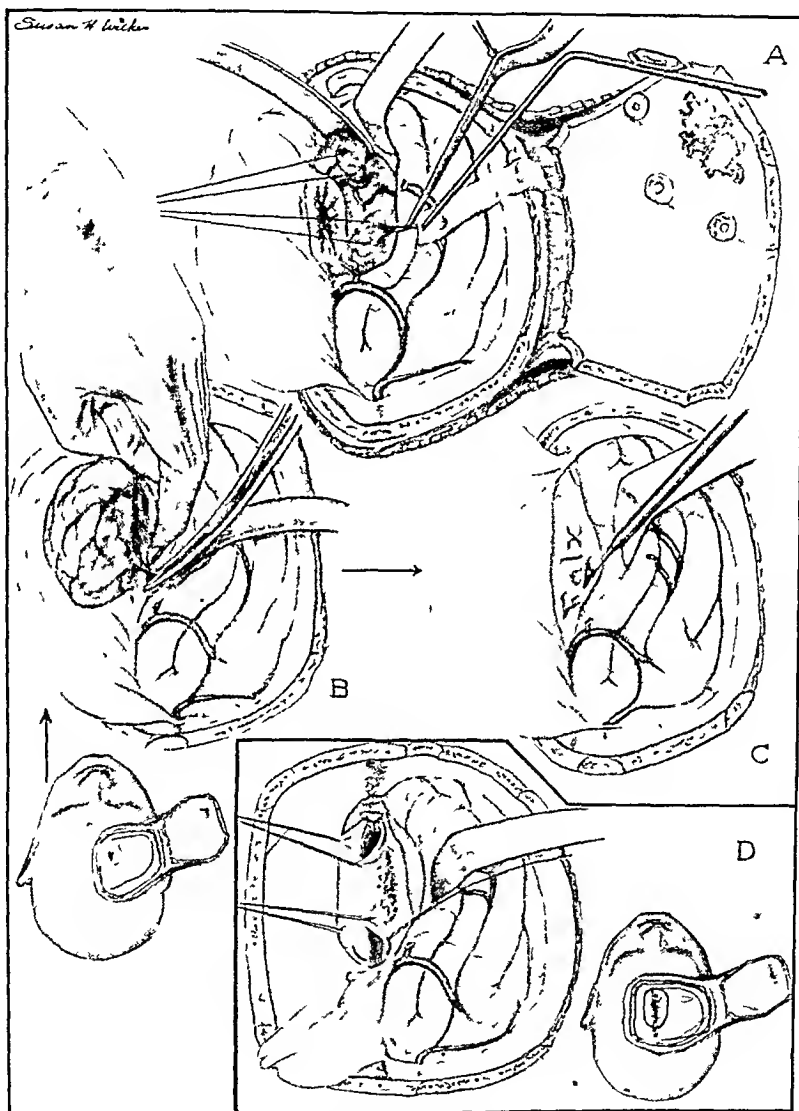


FIG. 63. Technical problems in parasagittal meningiomas. (A) Dural "stalk" is left on tumor, which is delivered toward midline. Area of invaded bone to be removed is indicated. (B) Placing a silver clip on a deep bridging vein. (C) Coagulation of bleeding point on falx (or of area of origin of tumor arising therefrom). (D)Ligation of superior longitudinal sinus which has been invaded by tumor anterior to central sulcus (inset).

hinge medially (Figs. 62–63). The area of dural attachment to the tumor should be encircled by a separate dural incision (which may be circular or semicircular, depending upon proximity of the lesion to the midline) and left on the tumor. If the flap is sufficiently large, the margins of the surface of the lesion will then be readily accessible and its removal may be begun (Figs. 62–63).

A choice of two methods of removal of the global meningiomas must be made. One is the complete enucleation of the intact tumor, the other is excavation of the lesion through its exposed surface in order to reduce its size, collapse its capsule, and permit subsequent dissection and removal of the remaining shell. The choice will depend most upon the size of the tumor, although its location, its vascular connections, the adequacy of the exposure, and the extent of the presenting tumor surface must also be considered. In general, removal *in toto* is preferable if it can be accomplished without significant injury to the surrounding brain (Fig. 63). With very large tumors this is impossible and excavation (sometimes loosely called "uncapping") is essential (Fig. 62).

Excavation, if employed, should be done with the electrosurgical "loop," which is employed to "scallop" out the contents of the capsule bit by bit until the size of the lesion has been greatly reduced (Fig. 62). There will be free oozing of blood and occasional brisk arterial bleeding from the "scalloped" surface, but this may be controlled by gentle pressure with cotton in one place while further excavation is carried out in another.

Whether excavation has been employed or not, other steps in removal of the tumor are the same. Several deeply placed silk sutures in the tumor will serve to make traction and to elevate the lesion from its bed as the dissection proceeds (Fig. 62). If the tumor is attached to the longitudinal sinus

or the falx, the dissection should be begun at the periphery.[*] Here the bridging vessels between the pia and tumor are usually few and may be coagulated or clipped and divided without great difficulty (Fig. 63, A).

It is then possible, with traction on the tumor and gentle dissection with pledgets and strips of cotton, to elevate the tumor from its bed (Fig. 62, C) and deliver it on the hinge of its vascular dural attachment at the midline (or to deliver it completely in the case of the lateral tumors of the convexity). Deeper dissection may be done more gently and with less trauma to the adjacent brain by a dissecting finger (Fig. 63, B). This method has the additional advantage of palpation of bridging vessels in the depth of the tumor bed.

When the tumor is about to be delivered in this manner, division of the midline attachment introduces another critical phase of the procedure, since most of the vascular connections are through the dural "stalk." In most instances it will be necessary to shear the tumor from the falx or wall of the sinus by blunt dissection, leaving the inevitable fringe of neoplastic tissue on the dura.

It may be possible to control in advance large vessels traversing this "stalk," but usually there is free hemorrhage from the area of attachment and there may be an actual tear in the sinus wall. Control of bleeding is first attained by pressure upon cotton strips and subsequently by meticulous coagulation and application of muscle or fibrin foam soaked in thrombin solution.

During and subsequent to these hemostatic efforts, the remaining fragments of tumor are removed or thoroughly coagulated, including the entire surface of attachment (Fig. 63, C). Naturally this will be unnecessary if the area of origin has been lateral to the midline and conse-

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[*] This is contrary to the advice of Elsberg,[9] who stated that the vascular dural attachment should be freed first

quently removed with the tumor or if the sinus has been resected (cf. below).

At times there is considerable hemorrhage from pial vessels in the tumor bed. As soon as the mass is delivered, a pack of warm wet cotton should be placed in the cavity. This will usually serve to control the ooze of blood, but occasionally larger bleeders must be sought out by means of suction and coagulated. The brain expands very rapidly and even large cavities will be quickly reduced in size. Covering the walls of the cavity with thin sheets of fibrin foam has been done but will rarely be necessary.

Some meningiomas tend almost to bury themselves in the cortex and partial or complete transcortical exposure may be necessary. Tumors of the middle sphenoid region, for example, may burrow into the under surface of the temporal lobe and may be approached best by direct incision through the anterior portion of the temporal lobe (or by amputation of the temporal pole [cf. below]). Similarly, the convexity tumors, even after excavation, may require radial cortical incision.

Such incisions should be made through the pia with the cutting current, after coagulation of the pial vessels in the center of a convolution. Deeper extension of the incision is then carried out with blunt aluminum retractors until the surface of the tumor is reached and exposed. The exposed surfaces of the brain are protected by strips of cotton and are retracted as gently as possible. Such incisions should never be made in the motor cortex or in the lower posterior portion of the dominant frontal lobe.

The general principles just outlined are applicable to the removal of most globular meningiomas. However, a number of special situations require additional measures.

Large hyperostoses may require resection in a separate stage. Bleeding in such cases may be very serious and it is sometimes wise to remove the involved bone, with extracranial tumor, if present, and return for removal of the intracranial mass at a second session. Where feasible, the hyperostotic bone should be encircled by burr holes and the Gigli saw, with a wide margin of normal bone (Fig. 63, A). If the lesion extends across the midline, burr holes should be made just to each side anteriorly and posteriorly in order to minimize damage to the sinus. It will usually be necessary, in elevating the involved mass of bone, to dissect it away from the dura with a small sharp elevator. Bleeding from the dural surface and from the sinus must then be controlled with muscle or fibrin foam.

Involvement of the superior longitudinal sinus by invading tumor necessitates a decision as to whether or not the sinus should be resected. This procedure should be carried out (if the sinus is invaded) under two circumstances: first, if the involved area is well anterior to the point of drainage into the sinus of the rolandic vein, and secondly, further posteriorly *only* if the sinus is completely occluded by tumor. The latter point may be determined by puncture of the sinus with a fine hypodermic needle. Sudden occlusion of the patent sinus posterior to the rolandic area will nearly always result in *permanent paralysis of the legs or of all four extremities* or may result fatally. It should never be done.

If the sinus is to be resected, adequate removal of bone, either by reflection of an additional small bone flap across the midline or by rongeuring away sufficient bone, is essential. The dura must be opened up to the midline on both sides. It may sometimes be possible to do a complete removal of tumor and sinus *en bloc*,[1,9] but, with large tumors, the main neoplastic mass should be enucleated first and all bleeding controlled.

The sinus is then doubly ligated anteriorly and posteriorly with moderately heavy silk sutures and divided between the ligatures (Fig. 63, D). The falx is cut longi-

quire sacrifice of the entire flap is not uncommon and may not result in any serious complication. Replacement of such flaps body reaction and infection. Late repair of bone defects with tantalum or other substances (cf. Chapter 4) is always feasible,
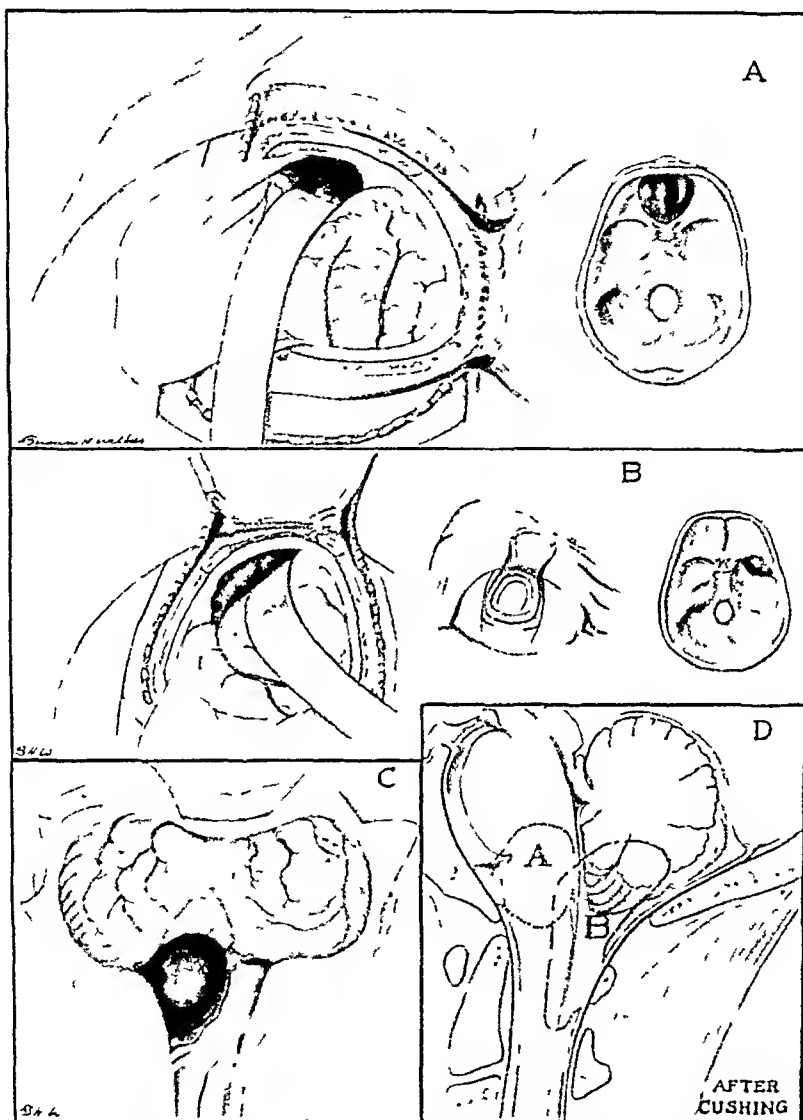


FIG. 64. Exposure of meningiomas of (A) olfactory groove, (B) outer sphenoid ridge, and (C) foramen magnum. (D) Usual sites of meningiomas of the posterior fossa. (Modified from Cushing.)

after boiling is a daring procedure, first suggested by Phemister[14] and Naffziger,[15] which involves considerable risk of foreign-and it is quite likely that, with improving methods, immediate repair in this way will soon be the method of choice.

Closure of the wound should be painstakingly carried out as described in Chapter 1. The wound should not be drained, particularly if a completely satisfactory dural closure has not been secured. Poppen's[17] method of holding the dura in apposition to the bone by means of sutures passed through drill holes in the flap is very useful and will no doubt sometimes avoid the development of extradural hematoma.

Replacement of blood requires exercise of the surgeon's experience and judgment. Premature rapid transfusion, producing rapid rise in blood pressure, may result in renewal of apparently controlled hemorrhage. On the other hand, delay in the presence of severe shock may actually terminate fatally. It must be remembered that a sudden fall in blood pressure frequently accompanies the actual enucleation of a large tumor, only to return to a normal level a short time after this traumatizing phase of the procedure has been completed. Nevertheless, it should be the rule that, when doubt exists, prompt transfusion is indicated The assistance of an anesthetist experienced in neurosurgical cases is invaluable in arriving at a decision regarding the wisdom of transfusion.

## POSTOPERATIVE FACTORS

In addition to the usual postoperative considerations discussed in Chapter 1, the meningiomas present other phenomena.

Convulsions, unfortunately, are all too common in both the immediate and the late postoperative periods. They may occur in patients who had no preoperative seizures. It is the author's practice to give phenobarbital or dilantin regularly from the time of operation and to insist on its continuance for from one to three years (or longer, if any cortical irritative phenomena occur).

Recurrence of symptoms due to continued growth of the lesion is very difficult of diagnosis in many cases. Late appearance of convulsions, with return of some preoperative symptoms, may be the result of cicatricial contracture at the tumor site instead of return of a mass of neoplastic tissue. In general, experience, careful observation, and a knowledge of the histologic nature of the tumor will determine the problem, but re-exploration should not be too long postponed if doubt exists.

In secondary procedures the problems of dense adhesions, diffuse tissue vascularity, and unexpected extensiveness of recurrent tumor add to the difficulties but are by no means insurmountable.

Recovery of function following relief of cerebral compression by a meningioma is often surprisingly rapid. The brilliant immediate result may easily lead to an unjustifiable optimism. Nevertheless, freedom from symptoms for many years is common and seemingly permanent cure is by no means rare.

## OTHER TUMORS OF MENINGES

The neoplasms of the meninges which do not fall within the category of the meningiomas are uncommon and are rarely amenable to surgical therapy.

Metastatic tumors, such as carcinoma, sarcoma, and melanoma, may involve the meninges, usually as part of general metastatic involvement of brain or skull or both. Rarely, metastatic plaques of these neoplasms occur as isolated lesions of dura or leptomeninx.

Interesting diffuse neoplasms of the lepteomeninges have been described under the titles "gliomatosis of the meninges" (Mahon[12]) and "sarcomatosis of the meninges" (Fried[11]).*

Plaques of true bone, which may be quite extensive, are occasionally laid down in the arachnoid (Pilcher[16]). These may well be related to the pacchionian granula-

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* Bailey and Bucy[3] include this lesion among the types of meningioma

tions and hence to the meningiomas. If symptoms are produced, surgical removal is indicated.

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# 9

# Tumors of Cranial Nerves*

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### OLFACTORY NERVES

As far as can be ascertained, no primary tumor of the olfactory, or first cranial, nerve has ever been reported. The usual lesions of this nerve, interfering with the sense of smell, are either traumatic (resulting from fracture of the skull) or pressure (from contiguous tumors). They also follow intracranial operations, especially transfrontal exposures, for operations on lesions about the optic chiasm. The contiguous tumors arising in the para-orbital or suprasellar regions may involve the olfactory nerve by pressure along the nerve or on the cribriform plate. Loss of smell may also be a symptom of intracranial tumors due to increased intracranial pressure. Sometimes one of the first symptoms of the presence of a meningioma of the anterior fossa is the loss of smell. Tumors of the pituitary gland at times compress the nerves sufficiently to produce partial or complete anosmia. Hence, while there are no primary tumors of the olfactory nerve, involvement of this nerve is sometimes of marked significance in the neurologic examination.

Loss of smell is, therefore, of primary diagnostic significance; while it does not indicate a tumor of the olfactory nerve, it may indicate a lesion or tumor situated in the neighborhood of the olfactory nerve or cribriform plate on the floor of the anterior fossa.

The surgical approach to the olfactory nerves is similar to that of the approach to the optic nerves. A transfrontal, intradural approach will expose the nerve from the bulb at the cribriform plate to its attachment to the brain.

### OPTIC NERVES

From a surgical standpoint the optic nerves are of great importance since they may be injured or destroyed (1) by trauma, (2) by a primary tumor of the nerve sheath, (3) by the direct pressure of neighborhood tumors, or (4) by increased intracranial pressure associated with the brain tumors or hydrocephalus. Fractures of the frontal bones extending along the roof of the orbit to the optic foramen may produce local hemorrhage, and occasionally this type of fracture may compress or actually tear the nerve.

Bullets traversing the floor of the anterior fossa may divide one or both optic nerves. Thus, from the surgical standpoint,

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it may be necessary to explore the optic nerves following trauma· from either head injuries or bullets entering the skull. The exposure of the optic nerves and chiasm is the same as for that of a pituitary tumor or for primary tumors of the optic chiasm.

Tumors. The gradual loss of vision in one or both eyes without evidence of pathologic changes within the eyeball should always suggest a tumor in or about the optic nerves or optic chiasm. All too frequently the neurosurgeon sees cases of blindness or impending blindness at such a late stage that surgical interference offers little prospect of restoration of vision.

Of all the cranial nerves involved in pathologic processes, the optic nerve is the most important and probably the most neglected. Fortunately, for the patients who are suffering from failing vision, ophthalmologists are now recognizing these lesions early and sending them to the neurosurgeon for exploration of the optic chiasm. There are many diagnostic aids in localizing the lesion, but frequently the history of slow, progressive loss of vision is of greatest diagnostic value. Patients who complain of running into the side of the door, or of being unable to see at either side, should immediately be suspected of having a lesion about the optic chiasm, such as a pituitary tumor, a meningioma compressing the nerve, or even a primary tumor of the optic chiasm or optic nerves.

Tumors affecting the optic nerve may be classified into (1) primary tumors of the nerve or its sheath; (2) metastatic infiltration of the nerve; (3) tumors of adjacent structures, either primary or metastatic; (4) brain tumors which press the optic nerve against the adjacent vessels; and (5) tumors causing increased intracranial pressure with resulting choked disks.

According to Davis,[1] primary tumors of

[1] Davis, F. A. Transactions of the Section on Opthalmology of AMA 1939 pp. 145–303.

the optic nerve can be classified into gliomas and endotheliomas. Gliomas arise within the nerve from abnormal proliferation of neuroglia cells. Since the nature of such tumors and the relation to von Recklinghausen's disease has been suggested, there is some controversy as to whether or not they are true gliomas, such as involve the brain, or whether they are fibrogliomatous proliferations. Regardless of whether or not they are true gliomas, an accurate diagnosis can be made only at the operating table. All patients in whom a tumor is suspected should be explored, since this affords the only positive means of determining the operability of the lesion. Sometimes it is possible to split the optic nerve and remove a portion of the tumor, thereby preserving part of the field of vision.

Metastatic tumors within the optic nerves are exceedingly rare, and have the clinical features of other tumors involving the optic nerve directly.

It is a well-known fact that a differential diagnosis between metastatic or primary tumors of the optic nerve and tumors of the contiguous structures pressing upon the optic nerve cannot be made except at the operating table.

The association of von Recklinghausen's disease and glioma of the optic chiasm is well borne out by a case quoted by Davis, upon whom one of the authors [W. M. C.] operated. This patient, aged 20, came to her physician because of failing vision and headache. She complained of rapid failure of vision in her right eye but very little in the left. There was bilateral optic atrophy upon ophthalmoscopic examination, the disk of the right eye being somewhat paler than that of the left. The visual fields revealed an atypical bitemporal hemianopsia. The field of the left eye for form and color showed a fairly typical temporal anopsia. The field of the right eye was much less typical. The vision in the left eye was 20/15 and the vision in the right eye was

20/200. The only significant feature of the general examination was the presence of a number of light, coffee-colored spots in the skin, scattered over various parts of the body. A presumptive diagnosis was made of von Recklinghausen's disease with involvement of the optic chiasm and extension into the right optic nerve.

Intracranial operation was carried out through a right transfrontal craniotomy. The right frontal lobe was elevated and the optic nerves and chiasm easily exposed. A large mass could be seen within the substance of the right optic nerve. In dissecting the mass free the left lateral portion was found to be cystic, and when it was punctured a yellowish fluid escaped allowing the collapse of the mesial portion of the tumor. Because the swelling extended to the right optic foramen, an attempt was made to unroof the right optic nerve. During the period of convalescence high-voltage roentgen therapy was administered in the hope of limiting the progress of the growth.

Endotheliomas, sometimes called meningiomas or arachnoid fibroblastomas, involve the sheath, the nerve itself being affected only indirectly by pressure. These tumors are similar to the endotheliomas found elsewhere in the brain and spinal cord, and microscopically show the same appearance with whorls of hyalinized connective tissue which have been called psammoma bodies. The origin of such tumors is still uncertain. It is not known whether they are truly primary growths which arise within the intra-orbital part of the sheath of the nerve, or merely extend into it from a similar growth within the cranium. It seems possible that these tumors may arise from cell nests imbedded in the dural sheath of the nerve, similar to those which appear in the cranial dura. The endothelioma of the optic nerve usually appears after the second decade of life.

The tumors which may simulate primary tumors of the optic nerve are those in the contiguous structures, and of these adenomas of the pituitary gland are probably the most common. They, of course, arise from the pituitary gland and project upward, compressing the nerve from below. Suprasellar cysts and hypophyseal-duct tumors also produce the same type of visual loss. Meningiomas arising from the tuberculum sellae and tumors arising about the optic chiasm may produce symptoms



FIG. 65. Primary tumor of right optic nerve showing diffuse, cylindrical enlargement of entire intracranial portion of optic nerve.

and objective findings which cannot be differentiated from primary tumors of the optic chiasm and optic nerve. These tumors are seldom accompanied by increased intracranial pressure, which distinguishes them from primary tumors of the brain, which produce secondary pressure upon the optic chiasm. Since the treatment of every type of tumor about the optic chiasm is surgical, and the diagnosis can be made only at the operation, a description of the gross appearance of these tumors is important.

Primary tumors of the optic chiasm and the optic nerve appear as a unilateral or bilateral bulbous swelling of the nerve (Fig. 65). Gliomas are usually characterized by

being smooth and seeming to infiltrate the nerve, whereas the endothelioma appears firm, round, or oval, and definitely encapsulated. They have the appearance of being attached to the optic nerve rather than being a part of the nerve itself. Their size varies from that of a small pea to that of a large olive.

ination, and both may have atypical perimetric-field changes. X-ray examination of the skull is extremely important, as erosion of the sella turcica, enlargement of the optic foramen, and erosion of the clinoid processes may lend valuable aid in differentiating the type and location of the tumor. For instance, if we have an enlarged sella
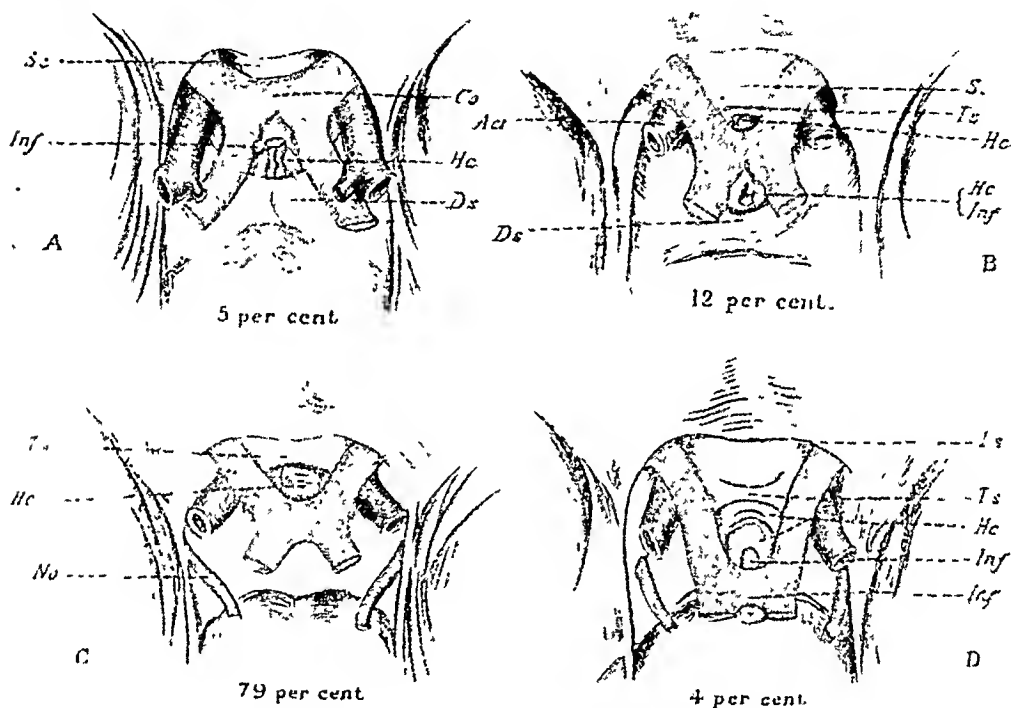


FIG. 66. Normal anatomic variations in position of optic chiasm. (After DeSchweinetz.)

The outstanding symptom of primary tumors of the optic chiasm is rapid progressive loss of vision. As elsewhere in the body a rapid loss of function usually indicates a rapidly growing tumor, as compared with the slow, progressive loss of function which is associated with the more benign type of tumor. Thus, in differentiating between the primary gliomas and the endotheliomas, the more rapid the loss of vision the more certain one can be that the lesion is a primary tumor. Both may be accompanied by optic atrophy upon ophthalmoscopic exam-

turcica, as evidenced by the roentgenogram of the head, one would think of an intrasellar tumor and one would look for a tumor involving the pituitary gland. Whenever the optic foramen is enlarged, one has to think of an endothelioma of the optic nerve, or of the region about one of the optic nerves.

Perimetric-field changes associated with tumors of the optic nerves cannot be adequately discussed without including lesions of the optic chiasm, due to the close anatomic relationship of these structures. In

Fig. 67

v o s 6/6 w.c.  v o d 6/12 w c.

3/330

5/330
(red)

Fund:

Left---Pallor I without loss of substance

Right--Pallor II without loss of substance

5/1000

2/1000
1/1000

roving
v o s objects  v o d 8/30

17/330  3/330

Fund:

Left---Pallor I without loss of substance

10 and 17
1000

5/1000
2/1000
1/1000

17/1000
2/1000
1/1000

v o s 6/20  v o d 6/12

3/330

Fund:

Left---Pallor I without loss of substance

Right--Pallor I without loss of substance

17/1000
2/1000
1/1000

v o s 6/12  v o d Amaurosis

20/330  3/330

Amaurosis

Fund:

Left---Pallor II without loss of substance

Right--Pallor IV, loss of substance II-III

35/1000
20/1000
2/1000

Amaurosis

Fig. 68

view of the fact that the position of the optic chiasm is not constant, a brief discussion of the perimetric-field changes associated with pituitary tumors will serve to illustrate the prechiasmal and the chiasmal as well as combined types of visual-field defects.

It is an established fact that the optic chiasm is not constant in its relation to the sella turcica (Fig. 66). In 5 per cent of cases the chiasm is far forward near the sulcus chiasmatis of the sphenoid bone. In such instances the intracranial extent of the optic nerves is extremely short. In contrast to this it was found that in 4 per cent of cases the optic chiasm was situated far posterior over the dorsum sellae. Such patients necessarily had long optic nerves. It is obvious that if the optic chiasm is far anterior, a pituitary tumor would present posterior to the chiasm between the optic tracts. Likewise if the chiasm were far posterior the tumor would present anterior between the optic nerves and might attain considerable size before the chiasm would be involved.

The great majority of patients possess an optic chiasm so situated that it becomes compressed in the early stages of development of a pituitary tumor. The most common defect of the visual field typical of an early chiasmal lesion is a bilateral upper-outer-quadrant depression for small test objects (Fig. 67, a). These changes are most readily demonstrated on the tangent screen at 1 or 2 meters. The defects progress clockwise in the field of vision of the right eye, and counterclockwise in the field of the left eye. In some instances the bitemporal defect is at first of the scotomatous type. The characteristic defect of a well-advanced tumor is a bitemporal hemianopia which at first is relative but later becomes absolute or dense to a test object of any size (Fig. 68, a). A bitemporal defect as such may persist for a long period of time, but if the pressure continues the nasal fields will become involved and blindness will ensue.

A tumor which presents well anterior to the optic chiasm between the optic nerves produces a prechiasmal type of defect of the visual fields, the essential feature of which is an early loss of central vision which is usually unilateral owing to the presence of a central scotoma (Fig. 67, b). As the tumor enlarges the optic chiasm itself becomes affected. The result is the usual bitemporal type of hemianopia plus the original central or cecocentral scotoma. The late result of such a process is usually amaurosis in one eye and a temporal hemianopia in the other (Fig. 68, b).

A chromophobe tumor which presents posterior to the optic chiasm between the optic tracts may produce a bitemporal hemianopia provided that the lesion remains adjacent to the chiasm with the bulk of the growth essentially in the midline. However, irregular extension may easily produce pressure on the optic tract on one side with a resultant homonymous hemianopia, usually of incongruous type.

In the early phases of pressure on the chiasm and optic nerves by a pituitary tumor, the optic disks usually appear normal ophthalmoscopically. Later pallor is visible, and, still later, loss of substance which gives rise to the appearance of simple optic atrophy.

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FIG. 67. (*Top*) Perimetric field changes with chiasmal lesions. Upper outer quadrant depression. Earliest evidence of developing chiasmal lesion. (*Bottom*) Chiasmal lesion with marked prechiasmal involvement on left.

FIG. 68. (*Top*) Complete bitemporal hemianopsia of a well-developed pituitary tumor. (*Bottom*) Late perimetric field changes demonstrating chiasmal lesion with complete prechiasmal involvement on right.

**Surgical Treatment of Tumors of Optic Nerve.** The operation can be carried out under either local or general anesthesia. If local anesthesia is desired a regional block of procaine, starting in at the base of the nose and carrying up longitudinally over the cranium about halfway along the vertex, can be instituted. The angle of injection is then extended downward toward the ear.

If general anesthesia is used, intratracheal ether anesthesia is desirable. The patient's head is shaved the night before operation. Induction is carried out under gas-oxygen anesthesia. As soon as sufficient relaxation has been obtained a McGill intratracheal tube is introduced and anesthesia maintained using open-drop ether. The scalp is prepared with one coat of ether and two coats of antiseptic. An outline of the incision should be made before the sterile drapes are applied.

The incision which gives adequate exposure begins at the base of the nose, is carried up the middle of the forehead, and along the midline to the coronal suture. The incision is then carried downward into the temporal region, anterior to the ear. Incision is made through the skin and galea and then the entire skin flap is reflected downward and anteriorly. This allows for the exposure of the right frontal bone and the attachment of the temporal muscle. A bone flap is then outlined through the periosteum and burr holes are made starting in the temporal region anteriorly, just above, and lateral to, the external ridge of the orbit. Another burr hole is made almost in the midline just above the frontal sinus and then the burr holes are carried out to outline a flap whose base is in the temporal region and attached to the temporal muscle. This flap is reflected by joining the burr holes by a Gigli saw.

The dura is then carefully dissected from the anterior edge of the skull entering the anterior fossa and carrying the dissection along the floor until the sphenoid ridge is encountered. Here the dura is divided and from this stage onward the exploration is carried out intradurally. By gently elevating the frontal lobe the optic nerves and optic chiasm are brought into view. Strips of cottonoid are used beneath the retractor to protect the brain and as soon as the dura is incised a lighted curved retractor is used to elevate the frontal lobe and expose the optic nerves and the optic chiasm. In order to make a differential diagnosis between an intraneural tumor and an extraneural tumor, it is important that sufficient exposure be obtained to explore both optic nerves and chiasm. A large craniotomy allows very adequate exposure of the anterior cranial fossa without undue pressure on the brain.

A fusiform enlargement of the optic nerve or optic chiasm should immediately suggest a glioma, whereas an irregular nodular appearance of the nerve would favor an endothelioma. The gliomas are not amenable to surgical removal, although at times they are cystic and when the enlargement seems to fluctuate it is worth while inserting a fine needle for aspiration. On the other hand, if we are dealing with an intraneural endothelioma, it is sometimes wise to split the nerve as frequently the tumor can be enucleated. If no primary lesion is found the entire sellar region should be carefully explored for an intra- or parasellar tumor such as an adenoma of the pituitary, a suprasellar meningioma, or an aneurysm of the internal cartoid artery.

X-ray therapy for primary tumors of the optic chiasm has never proved of great value. On the other hand, because of the fact that it has never been determined that gliomas of the optic chiasm and optic nerves are not radio-sensitive, it is probably worth while to give postoperative roentgen-ray therapy in the hope of securing additional benefits.

## OCULOMOTOR, TROCHLEAR AND ABDUCENT NERVES

These nerves should be considered together in view of the fact that they constitute the entire innervation of the eye muscles. Paralysis of the third, fourth, and sixth nerves, with normal ciliary function, is termed external ophthalmoplegia. Paralysis of the ciliary nerves, or the ciliary ganglion, supplied by the third nerve, is called internal ophthalmoplegia. Complete paralysis of all divisions of the third, fourth, and sixth nerves is termed total ophthalmoplegia.

Oculomotor Nerves. The oculomotor, or third pair of cranial nerves, divides into three branches: the superior branch supplies the superior rectus and the levator palpebrae superioris; the inferior branch innervates the internal rectus, the inferior rectus, and the inferior oblique; the ganglionic branch supplies the ciliary ganglion. All movements of the eye, except direct outward rotation, and the combined downward and outward movements, are thus the result of third-nerve stimulation. This nerve may be injured by direct pressure from an aneurysm of the internal carotid artery, or indirectly as the result of a severe head injury. Penetrating wounds of the anterior portion of the middle fossa may divide the third nerve, usually with associated injury to the fourth and the sixth.

Tumors of these nerves are very rare, although they do occur with generalized neurofibromatosis of van Recklinghausen's disease. Generalized von Recklinghausen's disease, with bilateral acoustic tumors, has been associated with a neurofibroma of the third nerve. These tumors are so rare that usually one thinks of a paralysis of the nerves of the eye in association with tumors originating in the middle fossa, hypophyseal adenomas, new growths within the orbit, metastatic tumors, and aneurysms of the internal carotid artery.

No surgical procedure has been directed toward the oculomotor nerve, the indication for operative intervention being entirely the correction or removal of the pathologic condition, causing the oculomotor symptoms.

Trochlear Nerves. The trochlear, or fourth pair of cranial nerves, supplies the superior oblique muscle turning the eye downward and outward. Isolated paralysis of this nerve is rare and is supposed to be generally of syphilitic origin. No tumors have been reported involving this nerve.

Abducent Nerves. The abducent, or sixth pair of cranial nerves, supplies only the external rectus muscle. Primary tumors of this nerve are very rare and are usually associated with von Recklinghausen's disease.

Sixth-nerve paralysis secondary to increased intracranial pressure is frequently observed, and is generally of no localizing value. Tumors arising within the pons may involve one or both nerves and produce early internal strabismus. Tumors within the orbit usually involve the sixth as well as the third nerve. There is on record no surgical treatment for primary tumor of the sixth nerve and any surgical treatment is directed toward the relief of the internal strabismus and diplopia.

## TRIGEMINAL NERVE

The trigeminal, or fifth, nerve has both a sensory and a motor function, although the former is of the greatest clinical importance. The trigeminal nerve is probably best known for tic douloureux or trigeminal neuralgia and most of the surgery directed toward this nerve is that of posterior division of the sensory root for the relief of trigeminal neuralgia. Thus, surgically, it is one of the most important of the cranial nerves.

However, the presence of tumors in the gasserian ganglion, and in the trigeminal nerve itself, is of less frequent occurrence.
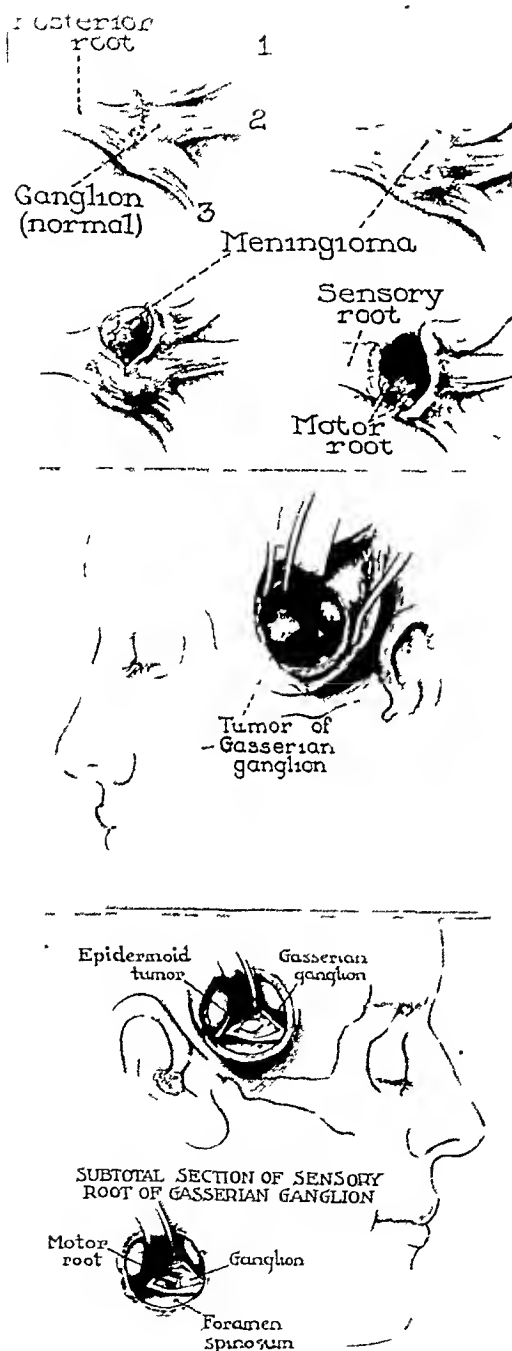
Tumors occur in the gasserian ganglion, or its sheath, in adjacent structures and by metastasis from distant lesions. Primary tumors usually include those originating in the nervous tissue and those arising in the dural sheath Here, as in the optic nerves, we may have either gliomas or endotheliomas, and added to this are the neurofibromas, either with or without von Recklinghausen's disease.

Of these three types of tumors, the endotheliomas of the dural sheath are the most common (Fig. 69). As a rule they originate on the superior surface of the ganglion and usually reach a large size before operation Secondary tumors may arise in adjacent structures and injure the ganglion by simple pressure or by direct infiltration Malignant growths within the nasopharynx not uncommonly erode the floor of the middle fossa and extend by direct continuity into the ganglion. Metastases from distant regions have also been occasionally reported. Metastatic carcinomas of the lung have been noted and in one case the finding of a metastasis in the gasserian ganglion was the first intimation of primary malignancy elsewhere in the body (Fig 70)

Epidermoid tumors have arisen posterior to the gasserian ganglion, producing all the symptoms of a primary tumor (Fig. 71) The classic syndrome of gasserian-ganglion tumors consists of severe pain associated with an onion-peel type of anesthesia in the distribution of the fifth nerve The pain is usually described as being of a severe lancinating type identical with the paroxysms of trigeminal neuralgia or of a severe constant burning character, often referred to the deeper structures of the face. The

FIG. 69. (*Top*) Gross appearance of meningioma of right gasserian ganglion and surgical removal

FIG. 70. (*Center*) Metastatic tumor of gasserian ganglion secondary to carcinoma of lung.

FIG. 71. (*Bottom*) Epidermoid tumor of right gasserian ganglion.

initial symptom is usually repeated paroxysms of severe pain indistinguishable from trigeminal neuraligia. But the spread of the pain and the course of the disease are much more rapid. The rate of progression of the symptoms depends upon the nature of the tumor. As a rule, endothelioma, or epidermoid tumor, produces symptoms by slow compression of the ganglion whereas

ralgia. A straight skin incision is made two fingersbreadth in front of the external auditory meatus beginning above at the level of the tip of the ear and extending downward to the zygoma The skin-deep fascia and the temporal muscles are divided and exposure obtained by means of a small mastoid retractor (Fig. 72). A burr hole is made in the temporal bone and this open-
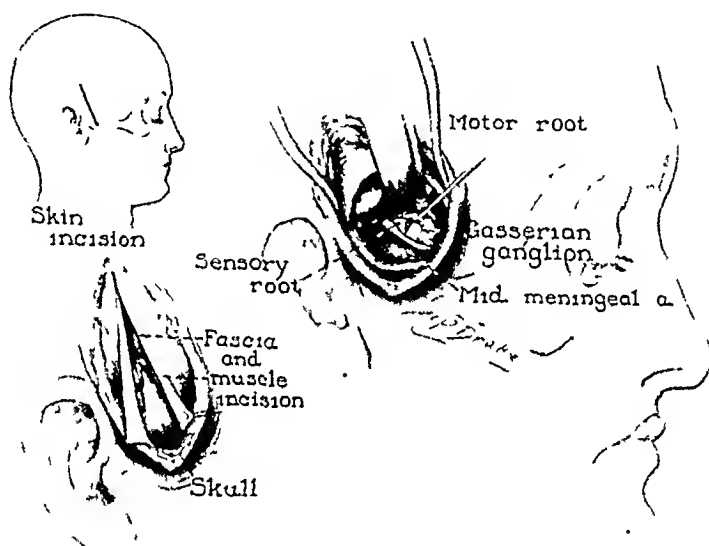


Fig. 72. Intracranial division of posterior root of right trigeminal nerve. Skin incision, surgical approach, and method of preservation of motor root.

metastatic and malignant tumors invade the ganglion and adjacent tissues with great rapidity.

The diagnosis of a tumor of the gasserian ganglion is based on the history of severe pain in the face, weakness of the muscles of mastication, loss of corneal sensation, and anesthesia in the distribution of the trigeminal nerve.

The treatment of all gasserian-ganglion tumors is surgical, and the same technic is employed as in the transtemporal resection of the posterior root of the gasserian ganglion for the relief of trigeminal neu-

ing is enlarged with rongeurs to about the size of a 50-cent piece. The dura is then gently dissected from the floor of the middle fossa until the foramen spinosum and the middle meningeal artery are visualized. The artery may then be either coagulated or ligated or the foramen spinosum may be plugged with wax or a wooden peg. The dissection is then carried forward and upward to the foramen ovale, through which the third branch of the trigeminal nerve makes its exit. Dissection of the dura from the third division exposes the inferior portion of the gasserian ganglion and it is only

at this stage that the pathologic diagnosis can be made with accuracy.

As in dealing with other intracranial tumors the technical features as well as the boldness of the surgical attack are governed by the pathologic nature of the lesion. Endotheliomas and epidermoid tumors should be extirpated as completely as possible, for their total removal ensures an excellent surgical result. Malignant lesions, on the other hand, may be removed if it can be simply done, but generally palliative section of the posterior root for the relief of pain is the procedure of choice.

## FACIAL NERVE

The seventh or facial nerve is of little surgical importance from the standpoint of primary tumors of the cranial nerves. No verified tumor has been reported although we had occasion to remove a large neurofibroma from the middle cranial fossa which may have had its origin from the seventh nerve since the patient's symptoms began with homolateral facial weakness.

Secondary involvement of the seventh nerve is not uncommon in cerebellopontine-angle tumors, basal-skull fractures, and during operations upon the mastoid.

## ACOUSTIC NERVE

Tumors of the eighth nerve are the most common neoplasms arising from the cranial nerves and represent over 10 per cent of all intracranial tumors. These benign encapsulated lesions arise from the sheath of the acoustic nerve and expand into the cerebellopontine angle.

Symptoms. Tumors of the eighth nerve are so consistent in their origin and development that they produce a pattern of symptoms and signs which is extremely constant, a feature which allows anatomic classification of the symptom complex.

Acoustic tumors arise from the vestibular portion of the eighth nerve within the porus acusticus. Growth of the lesion fills the cerebellopontine angle with resultant encroachment upon the adjacent cranial nerves, the cerebellum, and the medulla.

Disturbance of eighth-nerve function due to compression of the nerve within the internal auditory meatus ushers in the first phase of the syndrome. Progressive loss of hearing is usually the initial symptom, but often this is not appreciated by the patient until such time as other cranial nerves are involved. It is frequently stated by patients that they were not aware of the deafness until they attempted to use the telephone. This probably accounts for the earlier recognition of such lesions when the left nerve is affected.

Tinnitus is a frequent complaint and may antedate other symptoms by months. Description of this subjective disturbance is variable: a high-pitched ringing or the sound of a bell or escaping steam. The presence of an annoying tinnitus may lead to early ear investigation and discovery of the hearing loss long before it might otherwise have been noted.

The variation in the early evidence of a developing tumor is remarkable. One would expect corresponding subjective vestibular disturbance in view of the anatomic arrangement of the two portions of the nerve, but this is usually lacking. Occasionally one encounters a patient with deafness, tinnitus, and bouts of vertigo, such as are seen in Ménière's syndrome, who later proves to have an acoustic tumor, but this is certainly the exception to the usual clinical picture.

Paresthesias of the face usher in the second phase of the syndrome, the expansion of the tumor into the cerebellopontine angle. This evidence of fifth-nerve involvement generally precedes facial-nerve symptoms even though the seventh nerve occupies a position close to the site of origin of the tumor. Occasionally facial weakness is noted early if the patient is extremely ob-

servant, or if he used his cheek muscles to play some musical instrument. Slight facial weakness probably occurs very early, but is not recognized as promptly as the tingling and subjective numbness involving the face.

Symptoms of cerebellar dysfunction may precede the cranial-nerve symptoms but more often appear about the same time. The tumor by compression of the cerebellum disturbs the homolateral coordination of the extremities, particularly the leg. Unsteadiness of gait, tendency to vere to the side of the lesion in walking, and difficulty in maintaining balance when turning, are the outstanding subjective features of early cerebellar involvement. These symptoms generally become more prominent as the tumor enlarges. Incoordination of the upper extremity is noted but seldom assumes the severity of the homolateral leg.

Displacement and compression of the pons and medulla with obstruction of the free flow of cerebrospinal fluid from the third ventricle and resultant increased intracranial pressure represents the third stage of the syndrome. Headache, vomiting, and blurred vision result.

Clinical Signs. Objective evidence of involvement of the structures in the cerebellopontine angle follows a very constant anatomic and chronologic pattern. The clinical signs are so dependable that early diagnosis and localization should be made in most cases long before the tumor reaches serious proportions.

Stage of Cranial-nerve Involvement. This initial period in the tumor development is associated with few symptoms but sufficient signs to justify surgical intervention. Surgical results in this phase are most gratifying.

The function of the eighth, seventh, and fifth cranial nerves is impaired with resultant deafness, loss of vestibular response, facial weakness, and loss of corneal reflex on the side of the lesion (Fig. 73, a).

DEAFNESS of nerve type with loss of perception of higher tones, shortened or lessened bone conduction, and positive Rinne test.

VESTIBULAR RESPONSES. Caloric stimulation fails to produce any response from the vertical and horizontal canals on the side of the lesion, and later there is associated loss of the function of the vertical canals in the opposite ear.

FACIAL WEAKNESS. Asymmetry of the face, slight droop of the corner of the mouth, and loss of the nasolabial fold.

CORNEAL REFLEX. The corneal reflex is absent. No objective sensory loss can be detected in the trigeminal area, nor any weakness of the motor branch of the fifth nerve.

These few cranial-nerve signs are all-important and should be carefully watched for in any individual with progressive unexplained loss of hearing. It is true that other cranial nerves may, and later usually do, become involved in untreated cases, but they are of little diagnostic value from a surgical viewpoint because by that time the cerebellum has become so compressed that there is no doubt concerning the nature and site of the lesion.

Stage of Cerebellar Dysfunction. Growth of the tumor gradually fills the entire space between the petrous pyramid and the cerebellum. This relatively quiescent period may last months or even years, but cerebellar compression is inevitable and when it occurs signs of definite localizing value develop (Fig. 73, b).

ATAXIA. Muscular incoordinaation is generally first noted in the homolateral lower extremity. The patient becomes slightly unsteady in his gait, tends to vere to the side of the lesion in walking, and notes difficulty in turning. Later with progressive cerebellar involvement the gait may become so unsteady that the patient staggers.

NYSTAGMUS. Lateral gaze is associated with horizontal nystagmus in both eyes.

NYSTAGMUS

ROMBERG

INCOORDINATION

ATAXIA

V

VII

AUDITORY
VIII

VESTIBULAR
VIII
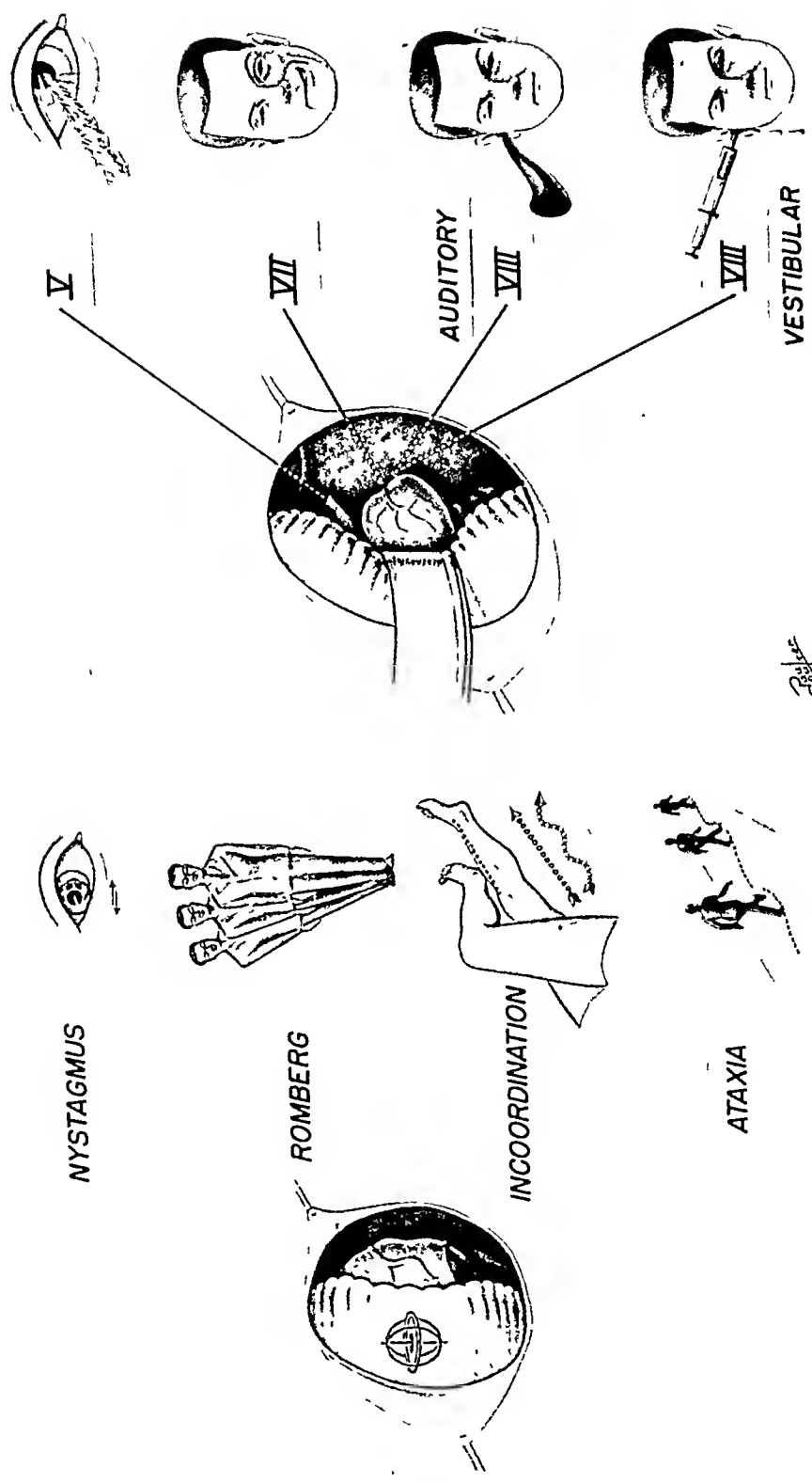
Fig. 73. (*Left*) Stage of cranial-nerve dysfunction. (*Right*) Stage of cerebellar dysfunction.

Slow and rapid components are early recognized but their direction is of no great diagnostic significance because of the other more important lateralizing signs.

INCOORDINATION. Unilateral impairment of coordinated movement is generally obvious and involves both the arm and leg. Rapid alternating movements are similarly impaired (adiadokocinesis).

nial pressure and internal hydrocephalus.

Developing obstruction is first evident by examination of the optic fundus. Dilatation of the veins and blurring of the nasal margins is soon followed by frank edema and elevation of the optic disks plus scattered hemorrhages and exudates (Fig. 74). During this period of generalized pressure weakness of the sixth nerve commonly de-



CHOKED DISC

DECALCIFICATION
AND EROSION OF
SELLA TURCICA

OBSTRUCTION
OF AQUADUCT
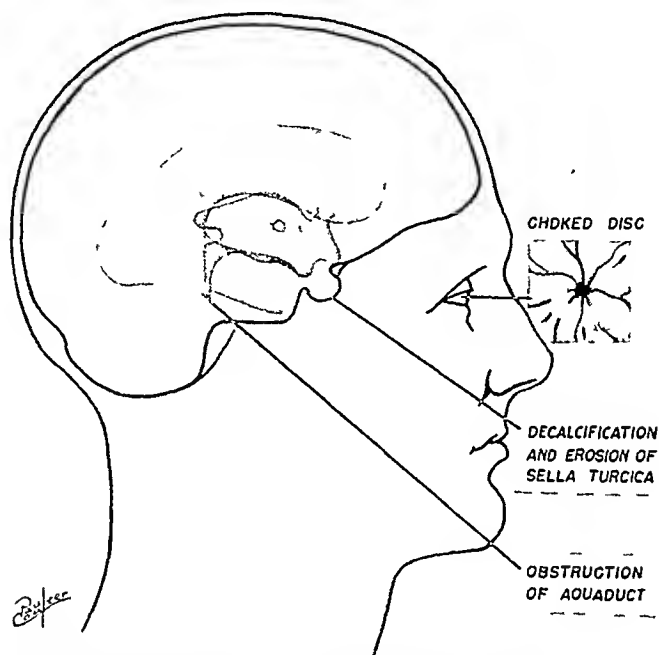
## VENTRICULAR OBSTRUCTION

FIG. 74. Stage of increased intracranial pressure.

A detailed discussion of cerebellar dysfunction has been purposely avoided. Many interesting features have been omitted in order to emphasize the essential diagnostic signs.

Stage of Increased Intracranial Pressure. Unfortunately, many patients pass into this late and serious phase before surgical measures are considered. Distortion and compression of the medulla and pons produces obstruction of the aqueduct of Sylvius with resultant increased intracra-

velops with loss of lateral motion of one or both eyes.

Diagnosis. Early recognition of a cerebellopontine-angle tumor should not be difficult. The cardinal symptoms and signs of eighth-, fifth-, and seventh-nerve involvement afford the accurate anatomic localization, while the gradual onset and progressive course establish the neoplastic character of the lesion.

Diagnosis should be made during the stage of cranial-nerve dysfunction and

usually can be established purely on the neurologic findings. X-ray evidence of enlargement of the internal acoustic meatus is merely a confirmative finding, but in some very early or atypical cases this roentgenographic evidence may be of the utmost diagnostic significance.

Neurofibromas of the eighth nerve are usually solitary, but bilateral tumors do occur The presence of pigmented areas of

deafness, tinnitus, and paresthesias of the face.

Increased intracranial pressure and internal hydrocephalus may produce secondary changes in areas of the brain remote from the cerebellopontine angle. At times these false localizing signs may be convincing enough to warrant further confirmation of the exact site of the tumor before surgical exploration. Ventriculography should



Fig 75. Multiple neurofibromas (von Recklinghausen's disease). Bilateral involvement of eighth, ninth, and tenth cranial nerves.

the skin and palpable tumors of the peripheral nerves should be looked for. Positive evidence of a generalized neurofibromatosis (von Recklinghausen) in a person with an intracranial lesion is presumptive evidence of an acoustic tumor (Fig. 75).

During the more advanced stages with marked cerebellar compression and internal hydrocephalus the clue to the correct diagnosis may be an accurate chronologic history. The situation may be indistinguishable from other space-occupying lesions of the posterior fossa until one gains the information that the illness began with

be employed in such cases for positive diagnosis of a posterior fossa lesion.

Differential Diagnosis. The problem of diagnosis differs in the various stages of this syndrome. The patient when seen early in the stage of cranial-nerve involvement may have deafness as the only evidence of a possible cerebellopontine-angle lesion The problem then is the nature of this lesion. During the stages of cerebellar dysfunction or hydrocephalus there is usually little doubt concerning the presence of a tumor, the chief concern being its exact location.

The diagnosis of tumor is most diffi-

cult in the early stages. At this period the tumor symptoms can easily be attributed to local inflammatory or vascular conditions of the internal ear. Otitis media may lead to localized arachnoiditis in the cerebellopontine angle with signs and symptoms almost indistinguishable from those produced by an acoustic tumor.

Otosclerosis, arteriosclerotic deafness, specific and nonspecific labyrinthitis, and toxic neuritis may cause some confusion in early diagnosis, but with careful investigation the differentiation should not be too difficult. Otosclerosis affects adults, commonly females, and produces a progressive bilateral inner-ear deafness associated with a minimum of vertigo. There appears to be a definite hereditary tendency. Arteriosclerotic deafness occurs bilaterally in older individuals with other evidence of arteriosclerosis. A careful general physical examination, including serologic investigation, generally suffices to identify the various types of labyrinthitis and toxic neuritis. Vertigo is more frequent and severe than with tumors.

Ménière's syndrome may offer some difficulty in diagnosis, but the occurrence of sudden severe bouts of vertigo with nausea and vomiting, deafness of nerve type with loss of high frequencies, combined with normal or hyperactive labyrinthian responses affords sufficient evidence for accurate differentiation. Tumors have been encountered that began with these identical findings but observation soon revealed progression of signs and symptoms that established the neoplastic character of the lesion.

Bilateral acoustic tumors do occur, and offer great difficulty in early diagnosis.

During the stages of cerebellar dysfunction and hydrocephalus there is usually no doubt of the presence of a space-occupying lesion, but often indecision as to the' exact nature and location.

Localized cystic arachnoiditis of the cere-bellopontine angle may mimic the signs and symptoms of tumor so completely that differentiation is impossible. Such a fluid collection in the angle also produces fluctuating symptoms so common with acoustic tumors. The majority of angle tumors are covered by an arachnoidal cyst which accounts in part for the similarity between these lesions.

Meningiomas develop in the cerebellopontine angle and produce all the signs of an acoustic tumor, but usually the loss of hearing is a late rather than an early symptom.

Cerebellar tumors rarely cause difficulty. The cranial-nerve signs are seldom a prominent part of the clinical picture. Cerebellar signs occur early.

Pontine tumors produce extensive cranial-nerve disturbance, usually early and bilateral. Pyramidal-tract involvement is greater than in other posterior fossa tumors.

Fourth-ventricle lesions are variable in their clinical evidence. Obstructive symptoms usually predominate. Seldom is cranial-nerve dysfunction an outstanding feature.

It not infrequently occurs that patients with obvious increased intracranial pressure are unable to give an accurate account of their early symptoms. Often they have had a known deafness in one ear for many years, the result of an old inflammatory or surgical condition. The first symptoms and signs may represent cerebellar dysfunction, and require surgical exploration to determine the exact location of the tumor. It is well to bear in mind that frontal-lobe lesions may present false localizing signs suggesting a cerebellar tumor. Long-standing hydrocephalus resulting from a posterior-fossa lesion may so dilate the third ventricle that chiasmal pressure results which produces a bitemporal-field defect suggesting a primary chiasmal lesion. Ventriculography must be resorted to under such

circumstances for accurate localization of the tumor.

Pathology. As viewed at operation the tumor presents a characteristic gross appearance. When the lateral margin of the cerebellum is retreated a glistening cystic membrane is encountered behind which is encapsulated a considerable amount of

erated tissue which presents a yellowish color. As a rule the tumor surface is richly covered with arterial branches from the basiliar artery and a plexus of friable veins. The eighth nerve is seldom seen when the tumor is large. The seventh nerve passes anterior to the tumor and is stretched and flattened. The fifth nerve is compressed and
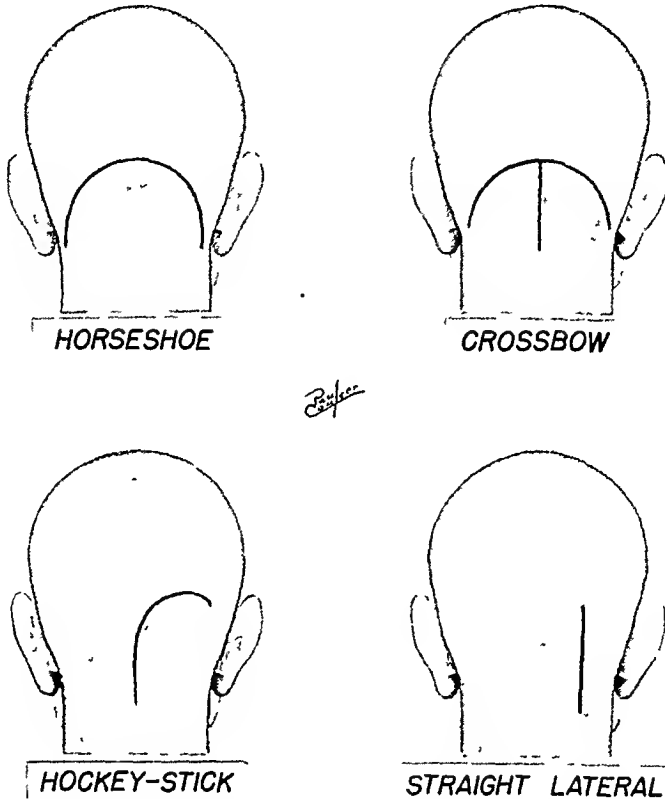


FIG. 76. Scalp incisions commonly used for suboccipital exploration.

cerebrospinal fluid. The fluid escapes as this arachnoidal membrane is opened, revealing a large pinkish-gray tumor mass completely filling the angle between the cerebellum and brain stem mesially, the petrous pyramid laterally, and the tentorium cerebelli superiorly. The capsule of the tumor is usually irregular and firm with many large localized areas of soft degen-

elongated by the superior margin of the tumor. The ninth, tenth, and eleventh nerves are seen at the inferior portion of the mass unless it has reached very large size.

Microscopic Appearance. Perineural fibrolastomas present a histologic appearance so consistent that recognition is relatively simple. The regular palisades of

large cells with elongated nuclei and the areas of degeneration with frequent cyst formation are the outstanding features. Whorl formation is seen especially about the vessels. Rather long fibers may be seen scattered throughout the field, but they possess no definite organization.

Neuromas are composed essentially of a mass of nerve fibers passing in bizarre directions through an abundance of connective tissue. Although palisading and whorls are present they form a very inconspicuous feature of the histologic picture.

Treatment. The only effective method of treatment is surgical removal, and no delay should be allowed once the diagnosis has been established. This point is emphasized because marked improvement may occur as the result of lumbar puncture done as a diagnostic procedure. A favorable response to this procedure may allay the fears of those not familiar with this fact, and allow valuable time to elapse before surgical intervention is decided upon. In fact, it can be stated that routine lumbar puncture is a hazardous procedure in such cases in spite of the temporary benefit that occasionally follows removal of cerebrospinal fluid. Deep x-ray treatment is contraindicated because acoustic tumors are not radiosensitive and a long course of therapy as a conservative measure allows progressive enlargement of the tumor, and thus adds to the subsequent surgical risk.

Preoperative Preparation of Patient. The evening before surgery sedation is valuable to eliminate restlessness and fear. The patient is in a better mental and physical condition for operation than if he were allowed to worry through a sleepless night. The morning of operation the patient's head is completely shaved. Two hours before surgery further sedation is given and just before being taken from his room he receives a subcutaneous injection of morphine and atropine.

Anesthesia. General anesthesia is pre-ferred. Induction is accomplished using a gas-oxygen mixture, and ether substituted as soon as possible in order to obtain sufficient relaxation for introduction of a Mc-Gill intratracheal tube. Anesthesia is continued with ether. The value of the intratracheal tube cannot be overemphasized. It ensures a free and adequate airway with improved control of the patient's respiration. Mucus can be removed from the bronchial tree by means of a catheter passed through the tube, thus preventing partial obstruction with resultant anoxia and increased concentration of carbon dioxide. The presence of either or both of these factors adds to the already elevated intracranial pressure, and may well decide the success of the entire operative procedure.

Position of Patient. The upright sitting position is by far the most favorable for any surgical procedure to be carried out in the posterior cranial fossa or cervical region. Venous congestion is at a minimum because the operative site is above heart level. Less blood is lost during exposure and cortical veins on the cerebellum are less apt to be injured. Visibility into the cerebellopontine angle is increased, the operation is done at eye level, and moderate retraction of the cerebellum affords maximum exposure. Visibility is further aided by the escape of blood by gravity which prevents accumulation at the bottom of the wound as is the case when the patient is operated in the old face-down horizontal position. The operative time is greatly reduced by elimination of much unnecessary use of suction. The upright position allows greater freedom to the anesthetist, and makes the veins of the upper extremities readily available for use in transfusions. Postural hypotension has been considered a disadvantage to the upright position, but since routine wrapping of the legs has been adopted, postural fall of blood pressure has been avoided.
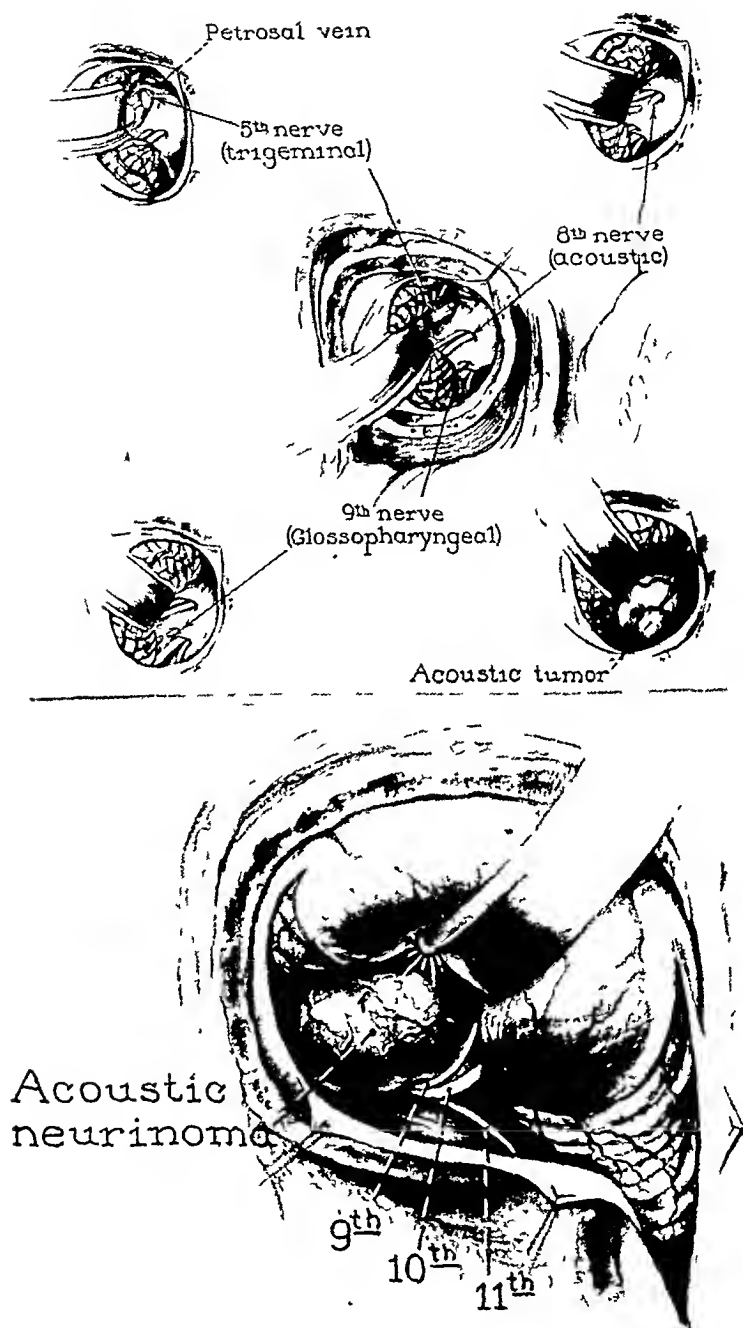
FIG. 77. (*Top*) Diagrammatic representation of surgical procedures carried out in cerebellopontine angle.

FIG. 78. (*Bottom*) Unilateral suboccipital craniotomy revealing a large left cerebellopontine angle tumor.

The patient is carefully placed on the operating table and the face fixed in the head rest. The scalp is prepared with soap and water, ether, alcohol, and an antiseptic solution. The proposed skin incision is lightly marked with the scalpel, and sterile drapes are applied and sutured in place allowing sufficient exposure over the occiput so that the lateral ventricle may be tapped.

Many types of incision have been proposed and each has had its enthusiastic supporters (Fig. 76). The old crossbow and horseshoe incisions gave very satisfactory exposure, but recently have been largely replaced by simpler methods. It is not necessary to carry out an extensive bilateral cerebellar decompression in order to remove an acoustic tumor. A straight lateral incision or an inverted hockeystick incision with the vertical limb in the midline have proved very satisfactory, the former being the procedure of choice.

**Operative Procedure.** A straight skin incision is made through the scalp and galea over the occiput and carried down into the upper lateral cervical region. Scalp clips are used to control bleeding in the scalp portion of the wound and pointed hemostats in the cervical area. The muscles are incised and separated from the suboccipital area of the skull from the midline as far lateral as the foramen of the mastoid emissary vein. Self-retraining retractors are fixed in place and wound towels are sutured over the skin and scalp margins.

A burr hole is made in the thin bone overlying the cerebellar hemisphere on the side of the tumor. This small opening is enlarged by rongeurs until an adequate craniotomy is obtained. It is essential that sufficient bone be removed including the lateral margin of the foramen magnum.

It will be noted after the bone has been removed that the dura is tense and normal pulsations absent, due to the increased intracranial pressure. Tapping of the lateral ventricle at this stage immediately reduces this pressure and allows one to open the dura without difficulty. The incision should be made close to and following the inferior and lateral margins of the craniotomy, thus retaining a flap of dura which can be utilized to protect the cerebellar hemisphere during the exploration of the cerebellopontine angle.

A lighted retractor is introduced gently between the cerebellum and petrous pyramid and the hemisphere is retracted mesially (Fig. 77). Moist cottonoid strips are used to protect the cerebellum. Resection of the lateral portion of the cerebellum may be necessary on rare occasions if adequate exposure cannot be obtained without excessive retraction.

Initial inspection of the angle seldom reveals the tumor, but rather a thin arachnoidal membrane covering a cystic collection of cerebrospinal fluid overlying the tumor. The cyst is opened, and as the fluid escapes the irregular pinkish-gray tumor can be seen filling the cerebellopontine angle (Fig. 78).

The decision as to the exact technic of removal depends on the size of the lesion and the experience of the surgeon. Complete removal is the procedure of choice if it can be accomplished with a minimum surgical risk. This can be done if the tumor is relatively small, but large lesions are best treated by intracapsular enucleation, although occasionally they too can be completely removed. Total extirpation usually is complicated by damage to the seventh nerve and complete facial paralysis. Subtotal intracapsular removal is a less radical procedure but carries with it the distinct possibility of a recurrence. Surgeons differ in their views regarding the most desirable method, but sound surgical judgment demands that the method be chosed that best meets the circumstances encountered in each individual patient.

TOTAL REMOVAL. The ninth, tenth, and eleventh nerves are carefully freed from

the lower margin of the tumor and protected by a moist cottonoid strip. The fifth nerve above may or may not be visualized, but if so it is separated from the tumor and a cottonoid strip placed between the nerve and tumor  It is seldom possible to visualize the seventh or eighth cranial nerves, as the former is usually on the under side of the mass and the eighth nerve is inti-

or the electrosurgical knife. Thorough intracapsular removal is accomplished, using various-sized curettes. As the interior of the tumor is curetted out, the capsule collapses, thus affording ample room for more adequate mobilization of the tumor. Extensive resection of the capsule usually can be accomplished in this manner without injury to the facial nerve
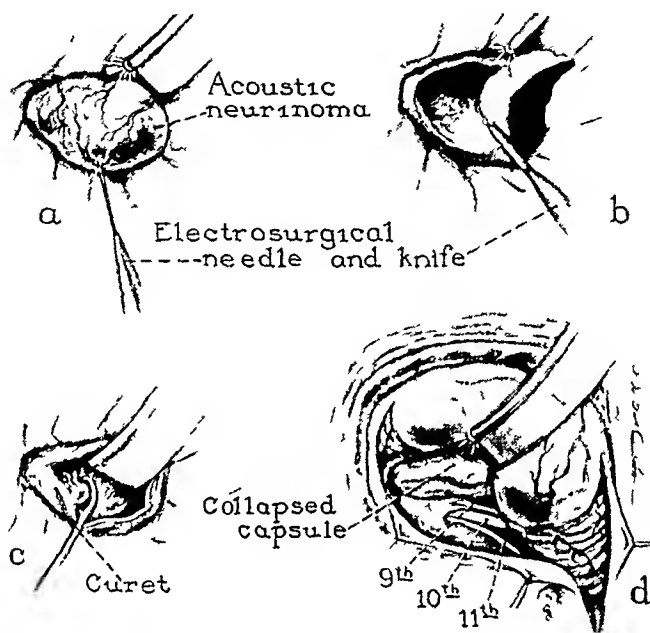


FIG  79. Method of intracapsular removal of an acoustic-nerve tumor.

mately incorporated in the tumor. The mass is gently mobilized and separated mesially and laterally as it is rocked in its position. An attempt is made to preserve the facial nerve, but this may be impossible.

INTRACAPSULAR ENUCLEATION. The ninth, tenth, and eleventh nerves are isolated and protected with cottonoid strips. A relatively avascular area is selected for incision of the capsule and coagulated to control bleeding from the small surface vessels (Fig. 79). A generous incision is made in the capsule with either a scalpel

COMBINED INTRACAPSULAR ENUCLEATION AND TOTAL REMOVAL. This procedure is adaptable to many large tumors, particularly those which have not become firmly adherent to the brain stem  Intracapsular removal of the bulk of the tumor allows the capsule to collapse, thus improving visibility in the operative field. The capsule can be grasped and gently teased away from the midline structures  Traction on the capsules allows the blood vessels to be drawn into view and accurately clipped before they are divided. Coagulation of vessels near the brain stem is a source of

grave danger due to the excessive heat developed. It is preferable to place moist cottonoid strips over the bleeder and apply suction and slight pressure on the strips for a few minutes until the hemorrhage is controlled. If electrocoagulation becomes necessary it should be brief as possible and immediately followed by irrigation with saline.

Control of Hemorrhage. The small points of bleeding, arterial or venous, can easily be controlled with the electrocoagulating unit. More extensive hemorrhage may require the use of silver clips. Occasionally a small opening may be torn in the lateral sinus which may require the use of a muscle pledget for adequate control. Recently fibrin foam and solutions of thrombin have been introduced and have proven to be of great value. The use of plain narrow gauze packing has been of aid in controlling extensive oozing and can be packed into the angle at the termination of the operation. The free end is brought out through a stab wound which allows removal after 24 hours.

Hemorrhage has seldom been of serious moment since adoption of the upright position for operation. Increased exposure and visibility make accurate control of the individual bleeders a less difficult and time-consuming task.

Wound Closure. The wound is closed in anatomic layers using catgut sutures in the muscles and silk in the galea and skin. Drainage of the wound using a small Penrose wick affords a smoother postoperative course.

Postoperative Care. Before the patient leaves the operating room a sterile catheter should be introduced into the intratracheal tube and by suction all mucus aspirated. The McGill tube may then be removed. A Buller shield is placed over the homolateral eye to protect the anesthetic cornea. The lateral ventricle may require tapping during the early postoperative period. The patient seldom requires but routine care after the first 24 hours.

# 10

# Intrinsic Tumors of Cerebrum

### Edgar F. Fincher, Jr., M.D.

## INTRODUCTION

There is no assumption of originality in the delineation of the surgery in this group of brain tumors. There are some personal preferences in the technical management of certain types of gliomas, but an attempt will be made to cover the procedures employed by various neurologic surgeons and the choice for routine adoption will be left to the reader's experience.

The technical problems begin with the patient's entrance into the operating theater. The proper selection of anesthesia, the patient's position on the operating table, the accurate placement of surgical drapes, the arrangement of the instrument tables, the accessibility of the electro-surgical unit, the suction outfit, the stationing of the active operating assistants, the intravenous infusion equipment, the lighting of both the operative field and the patient, are a few of the more common preliminary details to every craniotomy. More exacting particulars concerning these technical aids have been dealt with in the earlier part of this volume, and reiteration is only to emphasize the many details necessary for the betterment of technical accomplishments.

An x-ray view-box, as well as a blackboard, should be placed within easy visual range of the surgeon—the former for the skull radiograms of the subject under surgery; the latter for the routine recording of the patient's pulse, blood pressure, and

respirations at short intervals throughout the operation. With such routine charting, the surgeon and his operating team are continuously informed as to the patient's vital status.

Every craniotomy case should have an intravenous needle inserted before the scalp is draped, not only for the maintenance of the patient's fluid needs, but also for the speedy administration of blood. The hemorrhage problem is such in the intrinsic cerebral growths that blood replacement is necessary in most such craniotomies.

The surgeon must constantly bear in mind the clinical picture of his patient as he approaches the tumor. This approach is directed routinely by pneumo-encephalographic studies. To transect a normal-appearing cortex without pre-established proof of any underlying lesion is a malign practice. Since the intrinsic cerebral growths are in the minority of the group of "permanent cures," leaving the patient more seriously handicapped from his surgery can be avoided only by accurate anatomic symptoms. Any number of patients with grossly invaded left temporfrontal lobes have been able to carry on a comfortable and profitable living for lengthy periods of time after a craniotomy, simply because the surgeon recognized an astrocytoma as such and contented himself with a biopsy. Removal of frontal- and occipital-lobe lesions or of the right temporal lobes

results in fewer serious neurologic handicaps for the patient.

## SURGICAL PATHOLOGY

It was a master's opinion that the nature of the procedure appropriate to the particular kind of tumor necessitated a clear understanding of the life history of such a growth. Thus the surgeon should be not only thoroughly familiar with the gross pathology exposed on dural reflection or cortical transection in the operating room, but also he should himself be an able tumor histologist or have immediately available a competent pathologist. Not every neurosurgeon has access to such assistance, but a microscope can be set up in the operating room, frozen sections supplied, and the surgeon confirm his gross suspicions and choose the appropriate procedure in accordance with this histologic information. The present glioma classification is based on the dominating cell type, which serves as an accurate basis for prognosis and intelligent treatment. It is not within the scope of this chapter to enter into histologic details and only the more common gliomas will be considered in detail.

### GLIOBLASTOMA MULTIFORME

These are the most malignant of the cerebral gliomas, and constitute some 50 per cent of the intrinsic cerebral growths. Their most common location is in the left temporfrontal areas. The occipital lobe may seem to be the *locus* on ventricular air studies, only to have temporal-lobe invasion found at the time of surgical exposure. Not so easily localized clinically are the growths that have invaded the capsulothalamic area. These, incidentally, are more formidable surgical risks, and general anesthesia alone may result in prolonged unconsciousness or fatality.

These gliomas grow rapidly. For this reason, the intracranial pressure is increased

and quick dural opening or measures for temporarily reducing the intracerebral pressure are necessary to prevent cortical rupture. The dura is never involved directly in the neoplastic process. Adhesions to the underlying arachnoid or the pial veins may result from the intracranial pressure. Unless anticipated, tearing of these may result in a pial hemorrhage sufficient to mar the existing pathologic cortical changes.

These gliomas are very likely to be subcortical in location and so, upon dural reflection, an absence of subarachnoid fluid, a broadened anemic-appearing convolution or convolutions may be the only abnormal display. To the palpating finger a diminution in the normal resistance may be felt. Observation may reveal a surfacing of the growth as a yellowish-pink degenerative spot in a convolution. A large full temporal lobe with elevation and congestion of the middle cerebral venous channels may indicate an underlying glioblastic malignancy.

In a few cases, a demarcated obvious tumor mass may have replaced a convolutional area and so displaced the adjacent convolution as to make the operator hopeful of an isolated subpial growth (Fig. 80, A). As depth is gained on the demarcation, the true character of the lesion is found to be an invasive one. The surface tumor may appear rather firm, but as the cortical depths are reached the edematous, avascular, medullary substance is to be seen, or yellow "cancer-like" tissue is brought into view. Other areas may be richly supplied with blood and appear as soft substance that may be easily withdrawn through an aspirating needle or the vacuum suction tip.

In the more common deep-seated growths, one may on cortical section encounter at variable depths from the surface any one of several pathologic variances. A flattened, pale convolution may overlie a large cystic cavity from which 15
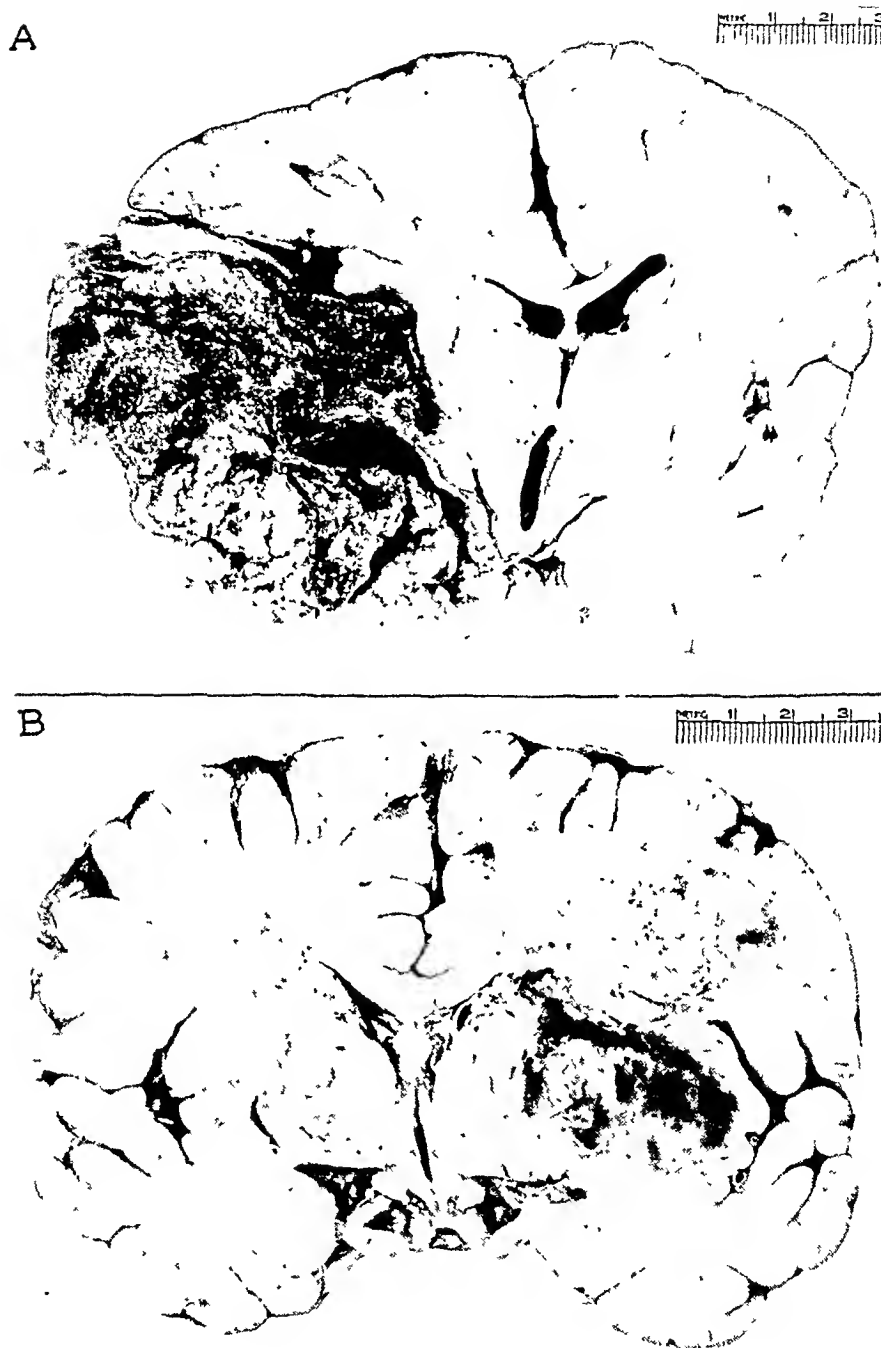
FIG. 80. Glioblastomas. The tumor destroys brain as it rapidly advances. (A) It may show a false line of demarcation while extending deeply into mid-brain. (B) It may infiltrate almost an entire hemisphere with relatively little ventricular deformity or displacement.

to 100 cc. of yellow, coagulable fluid may be obtained. Such large cavities are more likely to be within 1 to 2 cm. from the surface. Upon evacuation of the cavity nodular, grayish, reddened mounds will be seen. These granular irregularities are prone to bleed even with gentle instrumental manipulation. Smaller, 2- to 3-cc. cysts, may be encountered in other glioblastomas.

More frequently, at depths of 2 to 5 cm., one encounters first a mushy area of white matter, often of such a character that it can be wiped away with a cotton pledget. This zone is very narrow and one may enter spongy, honeycombed, toughened tissue that requires sharp curettement or electrical dissection. The area may be yellowish, of moderate denseness, avascular, and the curettings or "loopings" may have an appearance similar to that of a degenerated acoustic neuroma. Sooner or later as the dissection progresses in depth softened, vascular, beefy tumor tissue is encountered (Fig. 80, B). Bleeding from these areas is free, although rarely brisk. The demarcations within the cerebral substance are rarely sharply defined and ventricular entrance may be the first recognizable limitation of the neoplastic disease. These tumors consistently extend across the corpus callosum and "butterfly" the hemispheres. Neoplastic invasions in the glioblastomas, even with hemispheric sacrifices, always extend beyond gross tumor visualization.

In the progressive growth of this group of gliomas brain tissue is replaced rather than displaced. With this replacing characteristic it may be stated that the tumor vascularity is intrinsic. Larger arteries are to be found enmeshed in the neoplastic tissue. This is to be borne in mind in coring with sharp dissecting procedures. The cystic formations have been explained on the failure of vascularization to keep up with the rapidity of the development of the neoplastic cells.

## ASTROCYTOMAS

These are the benign fibrous group of intrinsic cerebral lesions and are the second largest group of the gliomas occurring within the cerebral substance. This subdivision, for surgical purposes, includes the astroblastic as well as the fibrous and protoplasmic glial growths. They, too, are hemispheric in location and, as the term implies, are reproductions of the supporting cellular elements of the central nervous system. The more common locations are in the temporal areas, although the motor and sensory areas are almost as frequently invaded—a fact of clinical importance that is to be stressed in more detail subsequently.

Occipital-lobe involvement is rare in these types. Although occasionally encountered as paraventricular lesions, by all odds the greatest number are to be seen as cortical lesions. If not frankly grossly involving the gray matter, the growth is likely to be within 1 to 2 cm. from the surface. Rarely does gross cerebral expansion occur as the dura is opened. The convolutional broadening in the astrocytomas is usually not that of frankly increased intracerebral pressure but is the result of tumor invasion, hence the gross appearance is that of an anemic, pale, broadened lemon- or salmon-colored flattened structure. The veins are small and the arteries are restricted to the sulci with a sparsity of pial arteriolar ramifications. The cortical tissues lend themselves to sharp dissection or instrumental handling without subpial soiling.

These gliomas are firm to palpation, unless one is over an underlying cystic disintegration, in which fluctuations may be encountered with the examining finger. A full temporal lobe, with sylvian vessels elevated, the convolutions flattened and of a shiny, mucinous, pearly-pink appearance, is the common appearance of an astrocytoma.

face growths are apt to be very firm and may not extend into the brain very deeply.

Although the bulk of an oligodendroglioma may be very firm, alternation of firmer and gelatinous consistencies may be seen in the same tumor. There are lesions in which 4- to 6-cm. cavitations may easily be accomplished with suction. Difficulty in recognizing the extensiveness of these tumors may be shown by persistent calcification in postoperative radiograms, even when a tremendous gross tumor removal was carried out. Therefore, at operation, the surgeon will do well to check his preoperative skull films.

### Ependymomas

These form an extremely small group. Although they are more common within the lateral or third ventricles, they are to be found within the cerebral hemispheres. In this latter location they are likely to be situated in a position adjacent to the ventricular walls. As in other gliomas there are microscopic variations that permit subclassification, but for practical surgical purposes they should be classed as a single group.

These growths within the cerebral substance are sharply demarcated from the normal brain, the surfaces are nodular; the consistency may be either firm or soft. Not infrequently there are small cysts which contain clear fluid. The "capsule" is very smooth and the surface vascular distribution is sparse. They may be of a dumbbell character, and, unless care is exercised, a lesion may be removed with the false concept (owing to its size) that a complete removal has been accomplished. Arising adjacent to the corpus callosum and present between the hemispheres, sharp delineation between the mesial cortex of the hemisphere and the tumor may exist. Once the tumor is entered the resemblance to the medulloblastic gliomas may be grossly misleading. A slate argyric color may shade into a nutmeg vascular area. Calcium whorls are common on microscopic sections, but are less frequent on the gross inspection. In children, exclusive of suprasellar cyst-wall calcium deposits, calcified areas of sufficient bulk to cast a positive x-ray shadow are likely to be in ependymal growths.

The ependymomas within the lateral ventricles attain rather formidable size before a diagnosis is made. They mold to the cavities which they expand by growth, as well as by ventricular blockage. Either enlarging and growing into both cavities or arising unilaterally they carry the septum into the opposite ventricle, to appear as a complete bilateral ventricular lesion. On more than one occasion bilateral ventricular punctures for air injection may be impossible because of such an ependymoma. In such an experience biopsy specimens are possible from both needles. Those growths located within the third ventricle rarely attain large size due to the early pressure phenomena resulting from obstructive hydrocephalus.

### Spongioblastoma Unipolare

This is a relatively benign group of gliomas rarely found as hemispheric lesions, but more common as pontine or cerebellar growths. On surgical exposure their color is somewhat grayish, the demarcation is more clearly defined than in even the astrocytomas, but not so acute as in the ependymal tumors. The growth of these tumors is rather slow and the tissue is somewhat avascular, but removal, as with oligodendrogliomas, is likely to be incomplete. Growing from the lateral wall of the third ventricle toward the mesial wall of the inferior horn of the temporal cavity, these tumors may attain enormous size.

### Pinealomas

Fortunately, this is an extremely small group. Since a greater number of these

growths extend posteriorly to involve the anterior vermis and occasionally into the anterior fourth ventricle, they might be considered borderline as to whether their location is intracerebral or not. At any rate many project beneath the corpus callosum, to appear as posterior third-ventricle defects on air studies. They may be very dense and so demarcated as to lend themselves to enucleation, others may be soft and the tissue consistency such that the attending hydrocephalus may be relieved by suction removal of the gross lesion.

## Medulloblastomas

These gliomas within the cerebrum have such a different career from those in the cerebellum that one questions the classification. From a surgical viewpoint the name serves a purpose and constitutes a percentage of cerebral gliomas larger than the ependymal growths and slightly less than the oligodendroglioma. It is to be remembered that in differential histologic studies in some instances certain elements not found in the classic cerebellar medulloblastomas of children are to be stained in these so-called cerebral lesions. Particularly is this true in the adult group, as compared to the grossly similar lesions in children.

In children their location is usually more posterior as compared with the paraventricular astrocytomas. Deep in the substance of the posterior temporal lobe or the anterior portion of the occipital lobe is their common location. Judging from average survival periods their growth is rapid in most instances. When first exposed there is a sharp differentiation between the white matter and the grayish tumor mass. Marked vascularity is usually very evident. Rarely is there brisk bleeding from individual vessels, but an oozing flow of frank arterial blood. The soft, mushy tissue is of the same character as are the cerebellar medulloblastomas. The rapidity of growth

of these cerebral tumors in children is not unlike those of cerebellar origin. In one experience transplants to the entire base of the brain and along the spinal cord occurred in a child who lived three years after her cystic subfrontal growth had been removed.

In the so-called medulloblastomas of adults, the right frontal and postcentral areas are common places of origin. Histologically the picture may be confused with oligodendroglioma, but with specific stains differentiation is relatively simple. In adults these embryonal cell growths apparently develop slowly. Grossly these growths may attain such size as to be confused with oligodendrogliomas. Cystic changes and calcium deposits are rare.

### Tumors Within Cerebral Ventricles

The ependymal and pineal growths have been alluded to. There are other growths and it is an encouraging fact that they are pathologically of a benign character. These tumors are the colloid cysts, the papillomas of the choroid plexus, and the meningiomas.

**Colloid Cysts.** The colloid cysts are of choroidal origin, are found in the anterior portion of the third ventricle, and usually block the foramen of Monro. They are small, mainly because early ventricular blockage and increased pressure are manifestations so intolerable as to spur patients to seek early surgical relief. On transventricular exploration they resemble a clear, domed lens, bulging through an enlarged foramen into the lateral ventricle.

**Papillomas of Choroid Plexus.** These are rarely encountered within the cerebral ventricles, being much more common in the fourth ventricle. They are tufted, reddened, mulberry growths that attain considerable size, but owing to cavity dilations they lie within the dilated lateral ventricle and may extend into the third ventricle.

**Meningiomas.** The meningiomas may attain alarming sizes (Fig. 81). They are

lateral-cavity growths and until the communication with the midventricle is obstructed may produce no objective symptoms. Such lesions arise and derive their blood supply from the choroidal vessels and their venous return is via the tributary vessels of the Galen system. Other lateral-cavity meningiomas may be adherent to the septum pellucidum. Irrespective of location or freedom of attachments their surgical appearance is that of a gray, nodular, toughened, benign growth which on

tensive elevations of the cerebrum on exposure are likely to occur. Often a small nodule a centimeter below a broadened convolution will be the single explanation for the alarmingly increased brain bulk. On palpation an isolated denseness is often a lead to a cancerous implant. The implanted growths are reproductions of their original neoplasms. Always sharply demarcated from the surrounding white matter the surfaces may be quite vascular and bleed freely. The melanomas are characteristi-
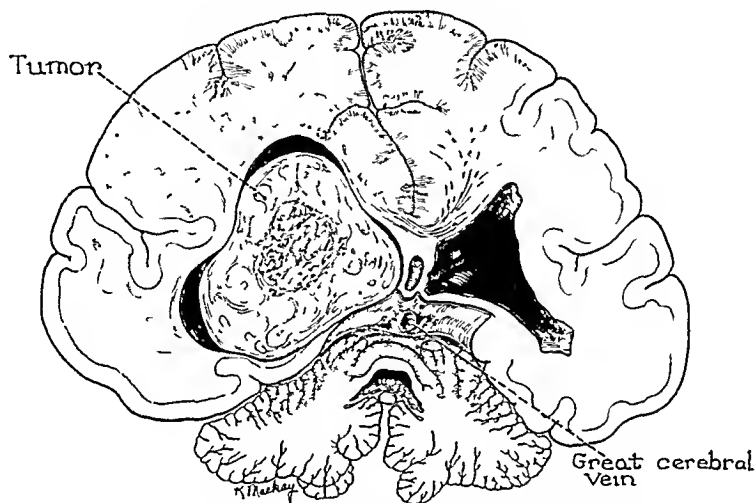


FIG. 81. Intraventricular meningioma. Tumor often lies free in ventricle except for its vascular attachment.

dissection is no different in character from the dural meningiomas.

### INTRINSICALLY LOCATED TUMORS: NOT OF GLIAL OR NEURAL ORIGIN

These growths comprise less than 10 per cent of the lesions under discussion. Included in these are the metastatic (carcinomas, sarcomas, melanomas) and granulomatous (tuberculomas, syphilomas, torulomas) lesions.

In the metastatic group, and particularly in the melanomas, migrations may be multiple. In these the intracerebral pressure is great, and cortical ruptures and extensive elevations of the cerebrum on ex-

cally chocolate-purple in appearance, may be of great size, and they, too, are hemorrhagic throughout; but as with other metastatic growths, when evacuated, the cavity bleeding is minor.

In the granulomatous group, torulomas of the cerebrum are a rarity and can be hastily passed by with the knowledge of their existence, and the fact that they may be multiple. Almost the same comment is applicable to tuberculomas, which, however, are more common than the granulomas of torula origin. While small tuberculous lesions may be multiple and cortically located, the larger space-occupy-

ing mass is to be found intracerebrally. In the syphilomas distinct pathologic pictures may be encountered in the operating room. The lesion may confine itself to a single convolution and replace such an area completely. These are early gummas. They are soft, red, beefy in appearance, and their consistency is only slightly greater to palpation than the adjacent normal convolutions. In more extensive invasions the lesion may resemble glioma, although the color belies this suspicion. In older gummas one encounters the densest and toughest of tumors. Such a granuloma is likely to present a small surface with the pial vessels about a "pork rind" center, and the greater diameter of the syphiloma is to be found beneath the overlying convolutions. Gummas are extremely rare and constitute less than 1 per cent of the intrinsic cerebral growths. They are not amenable to specific medical treatment and should be surgically removed.

## CLINICAL DISCUSSION

At one time in the history of neurosurgery it was a clinical rarity to venture a tumor diagnosis with a neurologic localization. At the present, however, a glioma diagnosis can be made with a fair degree of accuracy and the particular type of glial growth is also predictable.

Glioblastomas. The glioblastomas, the cancer of brain tumors, comprise a hopeless group in which surgical treatment can offer only symptomatic alleviation which is rarely complete, not always helpful to the victim, and never a permanent cure. Probably the most commonly and easily recognized of all brain tumors, they occur most frequently in the middle and latter decades of life. The rapid mental and speech symptoms are concomitant with the pressure phenomena of headaches and vomiting. The symptoms direct the attention of patient and observer to the brain as the possible site of disease.

The temporal lobe is the favorite area for these malignancies, and speech disturbances are frequent. Frontal-lobe invasions account for personality changes and indifference to responsibilities. Sphincter indifference, when present as an initial symptom, suggests callosal spread and bihemispheric involvement. This suggestive lead is supported by the tremors, erroneously ascribed to a corpus-callosal disturbance.

The frequency of headaches and vomiting is as common as the presence of swelling of the optic nerves. In a few cases mild papilledema or normal fundi may be present.

The average period from initial onset of symptoms until operation is about three months. The average survival period from onset of symptoms with operation is less than 12 months.

Astrocytomas. These are tumors of young adults. They are more hopeful both for longevity and for a useful, comfortable existence. Much more than symptomatic relief can be offered by the surgeon, and there are many five-, seven- and ten-year "cures." Their growth is extremely slow and insidious, which accounts for the latency of pressure symptoms. The duration of history may be anywhere from two to six or seven years. The great incidence of focal epilepsy in this group is due to their frequent development in the rolandic areas. Objective neurologic signs in the earlier cases are scarce. Unexplained convulsions in younger patients with mild subjective or objective intracranial-pressure changes may be due to a right-temporal astrocytoma. However, the absence of pressure changes is more misleading in the clinical diagnosis in this group of tumors than any of the other gliomas, a fact to be constantly kept in mind. These patients tolerate surgical procedures exceedingly well. Blood losses, extensive tissue sacrifices, and time-consuming efforts can

be met with none of the apprehensions involved with the gliobastomas.

Oligodendrogliomas. These are growths of the middle decades of life. A rare occurrence may be encountered in a child. Pressure symptoms may be the first clinical evidence of a tumor of enormous size. The "cotton-wool" calcium deposits in the radiograms may confirm the magnitude of such a growth. This suggests that they are most likely lesions of earlier decades. In a middle-aged person, with focal convulsions of two to three years' duration and the absence of any increased intracranial-pressure manifestations, an oligodendroglioma is to be suspected. Unlike the tremendous-sized tumors, the surface ones do not have radiopaque deposits, nor too great pneumographic defects. The survival periods after operation will average five years or better.

Ependymomas. Ependymomas appear in children and younger adults, and a complete enucleation is likely to effect a permanent cure. Those arising within the third ventricle cause early pressure symptoms. In the hemispheres localizing epileptic seizures or visual-field defects are common. The pressure findings are not so alarming.

Spongioblastomas. Spongioblastomas in the cerebrum present no such characteristic clinical picture. They usually occur in children. A high degree of intracranial pressure, no obvious localizing symptomatology, and an unusual pneumographic study would suggest such a pathologic diagnosis.

Pinealomas. These are primarily growths of young people. The clinical picture is that of intense intracranial pressure due to early hydrocephalus. Localizing symptoms are more frequently due to neighborhood encroachment and are misleading except for the corpora quadrigemina phenomenon—loss of upward eye movements. Bilateral deafness and decerebrate motor disturbances of varying degrees are common. A diagnosis can be ventured only after demonstration of the patient's inability to gaze

upward. The pubertas praecox picture is indicative of a teratomatous pineal lesion. Ventriculography with complete air filling is the only accurate preoperative diagnostic criterion. Were it not for response to x-ray therapy the survival period following operation would be materially shortened.

Medulloblastomas. These are found in children and young adults. The clinical picture is not characteristic. Localizing symptoms are rarely definite. Pressure symptoms leading to ventricular air studies allow properly placed osteoplastic exposures. Their clinical course is a short one in children, much more hopeful in adults.

Intraventricular Tumors. Intraventricular tumors, as a group, are benign growths, and, exclusive of ependymomas, present rather favorable outlooks. Pressure signs occur early as a result of fluid obstruction. The symptomatology is commonly that of recurring headaches with associated vomiting and transient attacks of blindness due to a "ball-valving" obstruction of the third ventricle. Visual-field involvement is more likely in the lateral-cavity lesions. Many complete surgical cures can be expected in the intraventricular tumors.

Granulomas. Torulomas. The torula lesions are extreme rarities and constitute more of a pathologic curiosity than a lesion for surgical consideration. The diagnosis is to be suspected from the previously established medical study, but pressure symptoms and localizing suggestions may lead to air visualization of a ventricular defect.

Tuberculomas. These are not so easily suspected clinically. Bizarre clinical pictures and intracranial-pressure evidence may prompt ventricular air studies. They are lesions of young adults and are very rarely encountered. Frequently a fatal tuberculous meningitis results months later from a similar lesion elsewhere in the central nervous system.

Syphilomas. The syphilomas, once considered a common cerebral lesion, occur in

less than 2 per cent of any large series of cerebral tumors. The results of surgical removal are most gratifying and recurrences do not take place. There is no uniform *locus*. Pressure symptoms precipitate the clinical diagnosis and air visualization the location. Antiluetic treatment is ineffective and the negative laboratory blood studies may be misleading in the diagnosis. The primary infectious history or provocative blood studies are helpful.

Metastatic Tumors. None of the common malignancies of the body fail to invade the cerebrum. The possibility of a metastasis should be suspected in any patient in whom a malign growth has been demonstrated and who presents evidence of a brain tumor. While bronchogenic carcinomas are very frequently transplanted into the cerebrum, melanotic growths are more common than is generally recognized —the former usually early after the primary diagnosis, the latter one to seven or eight years after initial recognition. Bladder and uterine growths may appear in the cerebrum as late as four to seven years after a removal of the original neoplasm. One laryngeal malignancy was uncovered eight years after a radical exclusion of the primary growth. The clinical neurologic pictures are variable but pressure symptoms are always present. The metastatic lesions in children are rare and are frequently a part of the clinical picture of a generalized body involvement.

## OPERATIVE METHODS

The technic of osteoplastic exploration has been discussed in Chapter 1 and is a fairly standardized procedure. Extensive exposures are dispensed with from a careful review of the ventriculograms, but once the cortex is exposed the operator may be said to be "on his own" and the technical surgery of the intracerebral lesion begins. It can only be stressed that every brain tumor is a "prize box" and the technical

methods applicable to one tumor may be totally wrong for another. One finds it extremely difficult to assign to particular pathologic groups a set routine, and what is to be said of any one type of glioma in the following paragraphs may be in part or all applicable to any of the intrinsic cerebral tumors.

Glioblastomas. In the glioblastomas choice of procedures is influenced by economic as well as physical factors. Less handicapped patients may be benefited temporarily by radical efforts, whereas others *in extremis* may be given a scientific diagnosis and prognosis without undue expense. Though there are individual cases in which trephine biopsy may be the only opportunity of establishing a diagnosis, the pitfalls and fallacies are probably greater than the risks and efforts entailed in those procedures that permit direct visualization.

If one is content with cannula biopsy, the technical undertaking is no greater than those of an ordinary ventricular air injection.* The election of the site for trephining should be made from a careful evaluation of the subjective and objective symptoms or from a careful study of ventricular air films. The ventricular needle and a well-fitted 2 cc. Luer syringe is all that is necessary. The cannula, on entrance into the tumor tissue, loses the mild resistance that one encounters in the normal brain tissue. It is well that the surgeon use the same type of cannula for every case, whether it be for ventricular punctures, biopsy, or exploration. Consistent utilization of the same blunt needle soon gives the surgeon a sense in his fingertips of any unusual resistance greater or less than he is accustomed to appreciate in normal cerebral tissues. Once in an abnormal field, the stilet is withdrawn, the syringe is attached to the cannula, and strong suction is exerted. One learns from a few early experiences the tension necessary for the extraction of normal

*Cf. Chapter 1.

cerebral tissue as compared with necrotic or neoplastic structures. The dural opening should be for the extent of the trephine limits, for insertion of the needle through a tight slit may obscure the sensation of differentiation between normal and pathologic areas.

The aspirated tissue is evacuated onto a cottonoid strip and washed with saline. Many times gross observation is of value in differentiating tumor from normal edematous tissue. A frozen section or a vitally stained tissue report must be made before further aspiration is done. Frank hemorrhage from the ordinary puncture of the cerebral cortex is rare, so much so that brisk bleeding from biopsy punctures offers some confirmation that a pathologic condition has been encountered. With a report of pathologic material sufficient biopsy material should be obtained for fixed tissue staining, since frozen tissue studies can easily be misinterpreted. Cotton-pledget pressure over the exposed cortex will soon arrest the escape of blood.

Subtemporal decompression and biopsy has the advantage of symptomatic relief and in many instances permits extensive tumor evacuation. The scalp, skull, and dural technicalities are the same as described elsewhere in this volume. The accurate selection of such cases is based on pneumographic studies. Disadvantages of this method may be ineffective release of intracranial pressure, compression of normal tissue against the bony edges, the unsightly herniation, and inadequacy of exposure.

Exposure by osteoplastic flap permits a more extensive visualization, minimizes re-
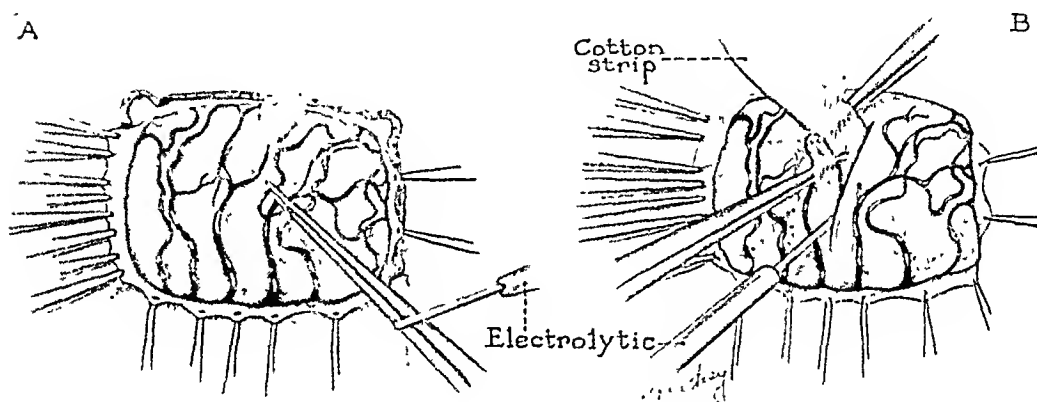


FIG. 82. Cortical incision. (A) Coagulation of cortical vessels. (B) Midconvolutional incision using the electrical cutting current.

traction upon normal convolutions, and permits removal of neoplastic tissues. A double row of deeply placed ligatures, double clippings, or coagulation of the vessels surrounding the lesion constitutes the first step. Using an electrolytic current for incision has the advantage of allowing a better gross differentiation between tumor and normal tissues. The tissue removal can be effected with sharp dissection when the tissue is firm and permits the use of "cupped" forceps; or, if it is soft and gelatinous, the suction apparatus is a more useful agent in clearing away the growth. The use of sharp curettes in certain lesions is just as useful as the electrosurgical loop for the removal of large strips from the wall of the tumor.

If the tumor is not visible on the surface, a calibrated exploring cannula introduced into the cerebral substance informs the surgeon of the depth of the lesion. An incision is made through the broadened convolution, the cortical edges and walls of white matter are protected with thin cottonoid strips, and the incision is deepened to the previously measured depth by blunt dissection (Fig. 82). Once neoplastic tissue is exposed, a goodly curettement for microscopic study should be removed (Fig. 83).

to or in the tumor. The parietal, prerolandic, rolandic, anterior cerebral, and middle cerebral arteries should be identified in their respective localities and damage to them avoided.

In performing lobe resections one prerequisite is a bone flap sufficiently large to permit wide exposure. For the sacrifice of the frontal lobe, dural exposure superiorly should be to the longitudinal sinus, anteriorly almost to the frontal pole, inferiorly to the sylvian cleft, and posteriorly to the

A

B
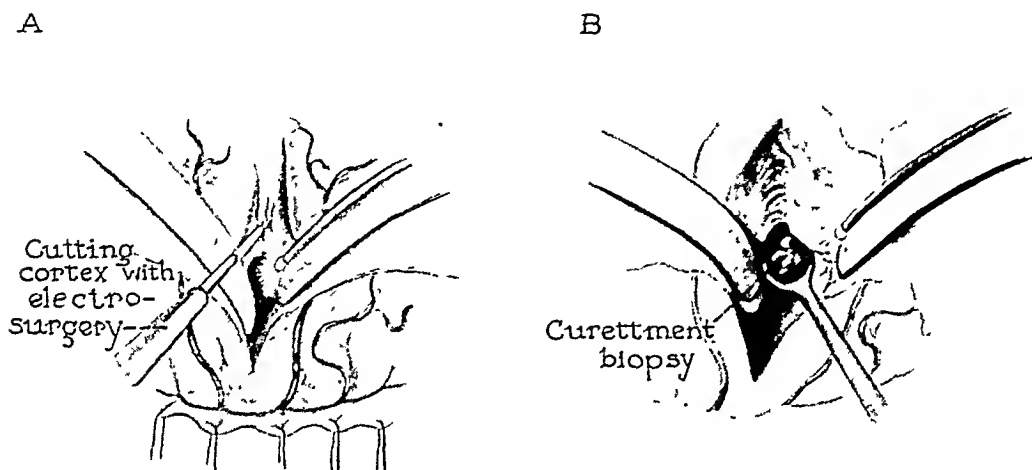


FIG. 83. Cortical incision. (A) Blunt dissection after initial pial incision, cortex protected with cotton strips. (B) Biopsy for frozen section as soon as surface of tumor is exposed.

Even if the lesion is a glioblastoma, gross tumor removal should be attempted, but never at the sacrifice of adjacent functioning cerebral tissues. The frontal, occipital, and temporal lobes when primarily involved may be evacuated of their neoplastic structures without adding new damage. In any case without aphasia and without paralyses an initial attempt at radical removal is justifiable. Secondary operation in these patients should never be done.

In addition to confining one's efforts to pathologic structures, it is necessary to spare the large arteries that lie adjacent

precentral sulcus if necessary (Fig. 84, inset). Coagulation of the frontal and prerolandic venous connections of the longitudinal sinus is easily accomplished or double sutures or the hemostatic clips may be utilized (Fig. 84, A). With lateral retraction of the hemisphere, protected by thin cottonoid strips and a flexible brain retractor or spoon, the anterior or surface of the corpus callosum is first identified (Fig. 88). The callosal marginal artery can be followed downward to the anterior cerebral and the latter clipped or coagulated. A properly placed hemostatic clip gives a

greater sense of security during the retraction. Both anterior cerebral arteries may be ligated without serious results, but, when one frontal lobe is already destroyed by tumor tissue, risk of avascularizing the opposite frontal area is to be avoided. The prerolandic artery is to be identified and its anterior branches interrupted. The frontal division of the orbitofrontal artery is iden-

middle fossa is possible. The three middle branches that ascend from the middle cerebral artery and the branches of the posterior cerebral artery to the inferior mesial surfaces of the lobe must be controlled.

Occipital-lobe resections require an exposure superiorly to the longitudinal sinus, anteriorly to the postrolandic sulcus, and inferiorly to the lateral sinus or tentorial
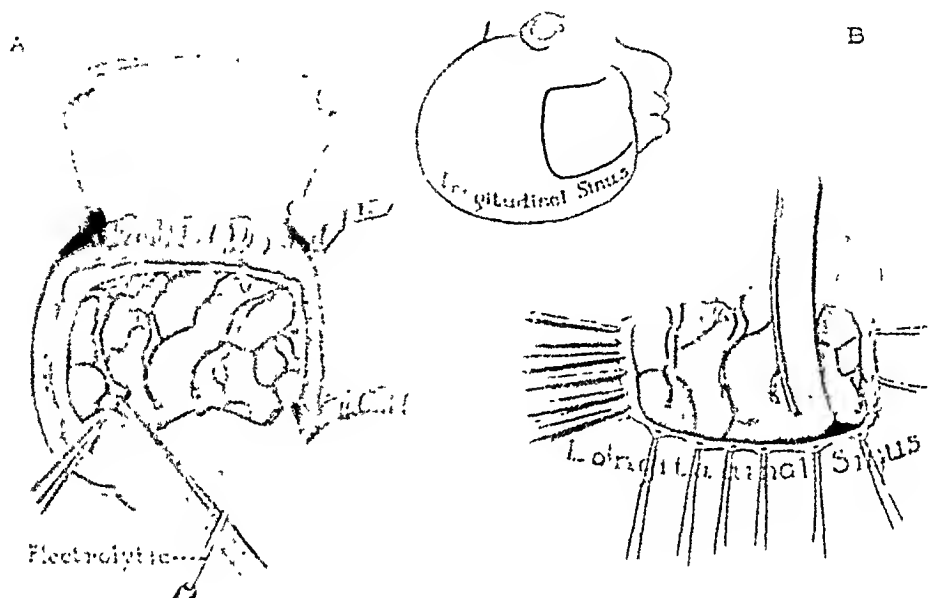


FIG. 84. Exposure for amputation of frontal lobe or division of corpus callosum. Veins entering longitudinal sinus must be carefully controlled and divided.

tified on the inferior posterior surface of the frontal lobe, but the orbital division is more likely to be encountered toward the end of the resection. It is technically impossible always to seek out these arterial divisions, but if the anterior cerebral and prerolandic arterial supplies are dispensed with before venous return is interrupted, cortical rupture is unlikely. Temporal-lobe resections require smaller bony exposures than any of the other area sacrifices, but do require that the anterior limb of the scalp incision go to the zygomatic level so that complete access to the floor of the

level. The large posterior occipital artery is buried in the depth of the calcarine fissure, and its final coagulation is usually possible only after the bulk of the lobe has been removed. The posterior parietal and angular arteries are ligated without risk. If the surface transection is across the inferior parietal area, one should take into account the right- or left-handedness of the patient.

Astrocytomas. Lobe resections and block removals are more often done in astrocytomas than in any of the other gliomas. Gross removal is always indicated,

provided one is conservative in the speech and motor territories. Although displaced by tumor bulk, anatomic structures are more easily identified and the more important arteries are more accessible. Since the astrocytomas are sparse in intrinsic blood supply, intratumor activities may be technically bold and vigorous without serious hemorrhage.

In cortical transection, a 4- to 5-cm. convolutional opening is more effective than working through an inadequate peephole

trocutting loopings are necessary. Sharp curetting is also an effective technical mode of ribboning out large quantities of toughened tissues.

So slow is the invasion in many cases that biopsy and decompression have permitted years of useful living. This is to be particularly borne in mind with motor and speech areas exposed and cannot be stressed too frequently. With the cystic changes that commonly occur, mural nodule removals are possible without block
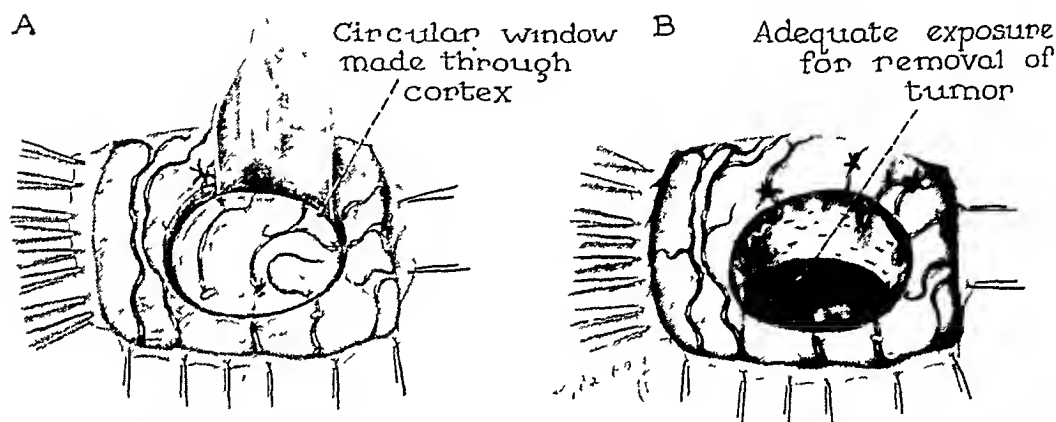


FIG. 85. Window excision for large, deeply placed tumor. (A) First step in uncapping over an underlying tumor. (B) Tumor exposure.

This latter narrow slit will end with more extensive surface trauma than is entailed in an original adequate, more lengthy incision; and, of course, will allow better visualization and room for more effective tissue removal, and will permit more surgical assistance from the members of the operating team (Figs. 82–83).

The metal suction tip with the attached or contacted electrosurgical unit has its greatest usefulness in this group of soft and gelatinous tumors. Many times astrocytoma tissue may be aspirated, leaving an arterial framework intact. Other astrocytomas of a more dense, fibrous, solid character do not lend themselves to vacuum removal. In these, sharp dissection or elec-

resection. Of course, if the nubbin is on the under side of a sacrificeable cortical area, external approach is more effective than attempts at working with a collapsing cavity.

Handicaps must be reckoned with in approaching the deep-seated paraventricular astrocytomas. To begin with, there is an acquired hydrocephalus, and if pressure relief is to be obtained this foraminal or aqueduct blockage must be released. Owing to the location of these growths disturbance of the floor of the third ventricle may result fatally. An approach by extensive frontal-lobe sacrifice is often best. Even mural growths are rendered more accessible by such lobe sacrifices. In the greater

number of these paramedial deeply situated growths in children, the lesion has grown to an excessive size and pressure relief will be the only surgical accomplishment. If the procedure does not release the hydrocephalus, the Tórkildsen tube from the posterior horn into the foramen magnum should be employed later.

Oligodendrogliomas. When deeply placed in the right frontal lobe biopsy confirmation should prompt a radical lobe sacrifice.

these growths is enormous, coring within the tumor to gain room for collapse of its limiting surface is essential. Owing to the toughness of the growth, sharp or electrical peelings are necessary. Suction is ineffective.

Ependymomas. In most cases convolutional transection is the best approach for the removal of these growths (Figs. 82, 83). If possible, without necessarily enlarging the cortical split to deliver the mass as a
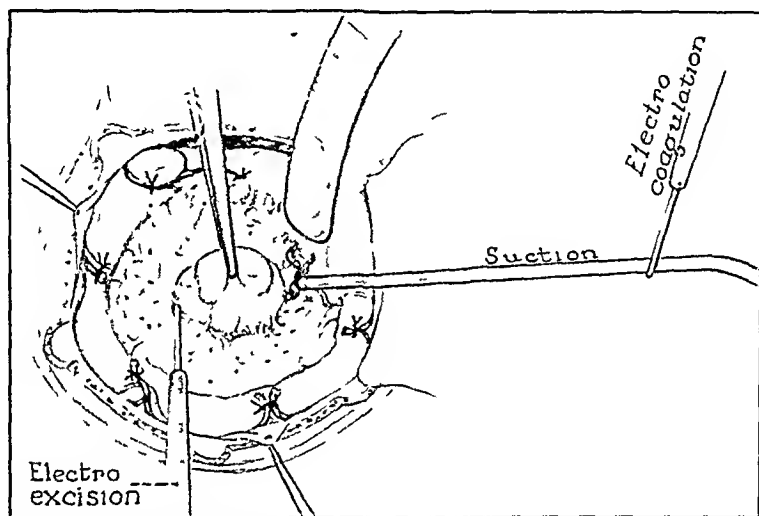


FIG. 86. Delivery of tumor by electrical dissection. Bleeding, controlled by suction-coagulation.

For those demarcated, smaller growths located on the surface which are adjacent to motor or sensory convolutions the setting is perfect for a complete gross removal. Circumscribed hemostasis is first accomplished. Once the vessels are severed blunt dissection will allow a peeling delivery of the firm pathologic growth. The tissue itself is too resistant for blunt dissection, so that differentiation from the underlying white matter is easy.

In the more common subcortical oligodendrogliomas, an unroofing exposure (Figs. 85–86) is better than a single convolutional transection. Since the size of

single specimen, stringed cotton pledgets fed in and about the circumference of the growth act as dissectors and as hemostatic agents, and when carried beneath the greater circumference serve to deliver the mass nearer the surface.

If the size of the demarcated ependymoma be too great for total deliverance through the cortical opening, or if it means too extensive surface-tissue sacrifices, several procedures are open to trial: a coring of the central portion of the tumor or the removal of a wedge of the growth so as to be able to fold the reduced tumor on to itself. If a needle attachment for the co-

agulating electrical outfit be used, with punctures of 1- to 1½-inch depths at a distance of ⅜ inch apart, coagulation and destruction of tumor tissue can be carried out. Tumor shrinkage occurs and evacuation of sufficient central material for capsular infolding is accomplished.

Pituitary cup forceps are an important adjunct in grasping the edges of a centrally evacuated tumor. Traction can be maintained without crushing through the friable tissues, as is common with small ordinary tissue forceps. Such traction permits teasing of the growth toward the surface as its cerebral encasement is overcome.

For those tumors lying between the hemispheres as subparasagittal growths, the surgeon is concerned with the ligation of the bridging cortical veins. These may directly overlie the growth or interfere with lateral retraction of the hemisphere from the falx. Once the surface of the tumor is exposed, gentle dissection is less destructive and less hemorrhagic than crude finger enucleation.

Medulloblastomas. In the soft, almost mucinous, types of gliomas, exposure by transection is effective. Since the tissue can be rapidly removed by suction, a working area is speedily gained. Using a lighted retractor and cotton strips for cortical protection, complete gross extirpations are possible without resorting to sharp dissection (Fig. 83). If the ventricle is entered, early fulguration of the choroid plexus should be done. This may obviate very brisk hemorrhage later. For anterior frontal tumors the inferior surfaces of the lobe are likely to be primarily involved and can best be approached and a gross removal be more accurately visualized by lobectomy.

Intraventricular Tumors. The technical effort in approaching and removing these tumors is likely to be lengthy and tedious. They are a surprisingly benign group. Except for the lateral-ventricle ependymomas and the lesions in the posterior third ventricle, the remainder are a very approach-

able lot. Only with ventriculography is accurate preoperative localization possible, and complete ventricular filling is more important than in some of the larger hemispheric growths. Anatomic disorientation, once within the ventricular cavities, is likely to be so disturbing that, without the positive preoperatively established presence and size of the space-occupying lesion, surgical explorations within these confines would be discouraging undertakings.

In the surgical approach to the third ventricle, transcallosal or transventricular incision or frontal or occipital lobectomy are (with opening of the lateral ventricles) the three orthodox routes. The sacrifice of a frontal lobe need not extend beyond the level of the inferior ventricular floor, but in occipital-lobe sacrifices the tentorial floor must form the base of the exposure. For the pineal growths a section of the tentorium after occipital-lobe section is usually indicated if an effective pressure release is to be accomplished.

The easiest and perhaps the least damaging approach to the midcerebral ventricle is across the corpus callosum, with an extensive osteoplastic exposure of the entire frontal lobe (Figs. 84, 88). The dural opening should be parallel to and as close as possible to the superior sagittal sinus. The frontal veins are occluded and divided and the frontal lobe retracted. The rolandic vein itself is to be avoided. The patient's head may be parallel with the plane of the operating table, or his brow may be up bringing about a reduction in venous pressure and allowing gravity retraction of the frontal lobe. The actual transection of the corpus callosum is best carried out with a small blunt dissector (Fig 88). The only bleeding to be anticipated here is from trauma to the veins within the septum pellucidum. Since this structure is usually stretched from the lateral-ventricle dilatation, the dissector will enter the lateral cav-

ity. A narrow lighted retractor with cotton protection is inserted beneath the roof of this cavity to prevent a collapse of the cerebral bulk as the ventricular fluid is evacuated and to provide exposure within the ventricle.

In the colloid cysts, the domed translucent lesion is visualized in the enlarged foramen of Monro. With a small, blunt,

hemostatic clip or, if accurate coagulation is employed, damage to the floor of the mid-ventricle must be avoided. A small muscle stamp or "blood foam" is often more desirable than coagulation for the control of plexus bleeding. In the larger colloid or papillomatous growths in the anterior third cavity a rupture of the cyst wall or a collection of the papilloma into the metal suc-
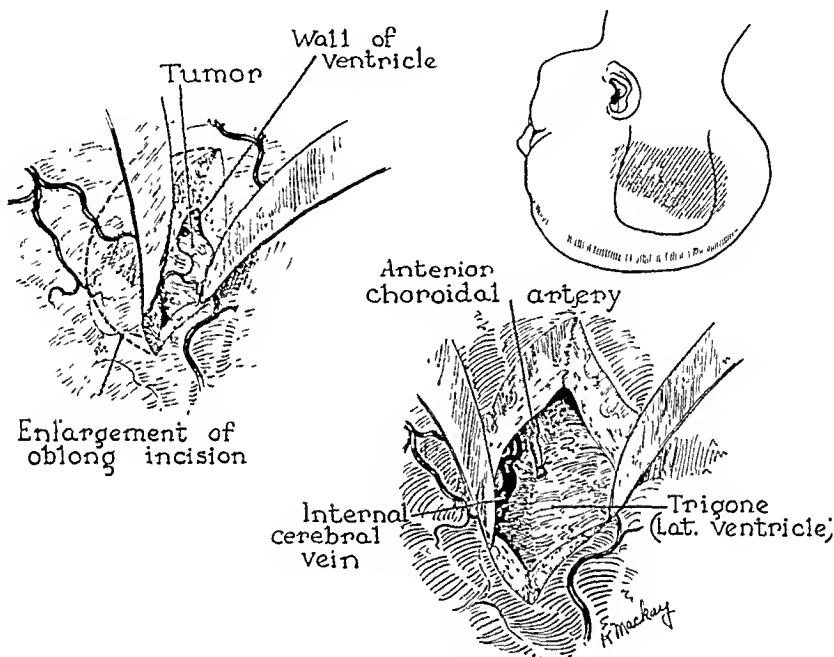


FIG. 87. Removal of intraventricular tumor through a transcortical incision.

right-angled dissector, this rounded inter-ventricular communication can be enlarged. This should be done before any manipulation of the cyst wall is attempted. These cysts are in most instances of relatively small size and can be laterally or superiorly exposed with blunt dissection. The demarcation of the cyst from the enveloping ventricular wall is very distinct. If the cyst can be gently teased away from its location, the vascular choroidal attachment is easily identified. Since retraction on this pedicle will permit a properly placed

tion tip may prove more effective than circumscribed dissection.

In the more solid growths within the third ventricle the enucleation is attended by more adjacent and more annoying hemorrhage. With slow, firm traction on its wall with cupped forceps, the growth can often be rocked in its bed. A 1-cm. vacuum suction cup applied to the surface of the tumor may net the necessary pull on the tumor mass. Gentle dissection with cotton will then disclose the relative size of the growth. If the mass is too large for easy

delivery a needle may be repeatedly inserted to a safe depth, and thorough coagulation to a degree of charring can be done. Tumor shrinkage and minimization of the tumor bleeding is thus obtained. Final delivery of the capsule or the cored shell is effected with traction and further cotton dissection about the capsule. A saline-soaked cotton pack in the tumor bed is effective if the bleeding is profuse. Muscle stamp hemostasis is more desirable in

Transtemporal exposures with convolution section rather than large cortical sacrifices permit ample room for the removal of even very large tumors. If the tumor be attached to the septum pellucidum, projecting free into the dilated lateral ventricle, it can be more effectively attacked through a transfrontal approach.

In utilizing transections, after a tumor extirpation a few well-placed, small, absorbable sutures (No. 000 gut on a No. 1
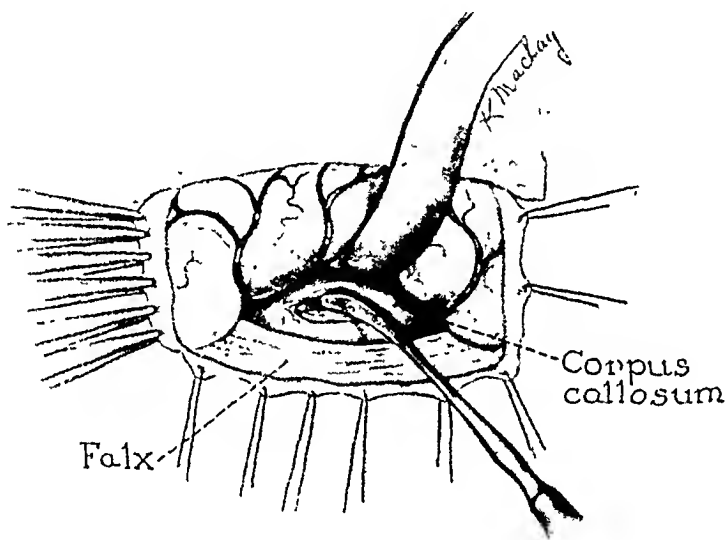


Fig. 88. Section of corpus callosum. (Cf. Fig. 83.)

this area than silver clips. Electrocoagulation for this bleeding is a dangerous practice.

The dissatisfactions of earlier experiences with midventricle tumors can best be overcome by utilizing collosal sections for the small ball valve, anteriorly placed lesions, and utilizing occipital-lobe sacrifices with a combined tentorial section when indicated for the larger posteriorly situated growths.

For the tumors primarily within the lateral cavities, exclusive of those that mold themselves as extensive bilateral lesions, air visualization directs the proper approach.

French-eye needle) should be used in approximating the pial edges of the cortical incisions. Before the last suture is tied the ventricles can be filled with saline solution and massive cortical collapse prevented.

Such technical procedures, applicable to the more common growths, are in part or in combination applicable to the surgery of the rarer tumors. Neuroblastomas are rare experiences for the neurosurgeon. Sharply demarcated, of benign character, they may have attained a dangerous surgical size at the time of the craniotomy. Coring of the mass centrally, followed by capsular retraction and cotton-pledget dissection from

the surrounding cerebral tissue, results in less destruction of the functioning tissues than do attempts at digital evacuation. The surgical maneuvers useful in astrocytomas will be as potent in their application to the occasional unipolar spongioblastoma of the cerebrum.

Granulomas. In the early softer gummas prophylactic surface hemostasis is the first step. With an appropriate-sized brain spoon the gumma may then be "scooped out." In the older and more invasive gummatous lesions it is well to investigate the extensiveness of the subcortical expansiveness after the surface vascularity is disrupted. The adhered arachnoid is subpially dissected and with cotton pledgets the enveloping cerebral tissues are pushed away from the limiting capsule. Traction on sutures in the tough mass with gentle dissection will slowly deliver an embedded growth with surprisingly minimal hemorrhage.

In the tuberculous granulomas the technical problems are in the main those of enucleating subcortical lesions that are frankly demarcated. Removal *in toto* is always the maneuver of choice, and these lesions are rarely diagnosed on the initial venture. Ruptures are prone to precipitate infectious spread, for which thus far there are not specific prophylactic methods.

In the chronic encapsulated pyogenic tumor masses for which the deeper substances of the temporal lobe is a favorite *locus,* the risks of rupture nowadays is not so hazardous as it once was. If the mass is too extensive for removal as a whole, bivalving, wedging, or even central looping will permit complete extirpation. If free pus is spilled in any of these maneuvers, prophylactic topical medication will obviate the serious fatal sequelae which once marred tedious surgical efforts.

Metastatic Tumors. The extreme intracerebral pressure previously referred to is the most hazardous condition with which the surgeon must compete in dealing with these tumors. Ruptures of the cortical tissues and vessels may be so handicapping as to block any real efforts in extirpating the tumor mass. A rapid sacrifice of the osteoplastic flap and a tight closure of the scalp will in most instances be sufficient for the arrest of the massive venous bleeding and the arteriolar hemorrhage. This results in a pressure relief for the patient and usually in more extensive postoperative neurologic handicaps than existed prior to the craniotomy. It does, however, offer the surgeon an escape from a fatal operative hemorrhage.

The exploratory cannula, for ferreting the depth or the character of these underlying lesions, may prove a detrimental instrument, not so much in the more solid carcinomatous tissues as in the lymphoblastic or melanomatous growths. In the former the resulting deeper hemorrhage is usually from the engorged normal vessels that have been displaced, but in the more cellular, more rapidly growing secondary lesions the intrinsic vascularity is an additional hazard. Thus it is safer to approach these metastatic suspects with a cannula only to a degree of ascertaining the subcortical depth and not to attempt to learn their inner consistencies. With the depth accurately ascertained a small transection will be less disturbing and will permit a much more accurate gross diagnosis. If the surgeon's suspicions are confirmed on this inspection, a convolutional split is made. Again, in accordance with the consistency of the growth, block removal with a coring and subsequent capsular dissection may be the choice. Suction and electrocoagulation of the tumor substance may be indicated or lobectomy may be preferable.

## CONTROL OF HEMORRHAGE

This is the primary concern in every craniotomy, and even before such a case is scheduled for operation a suitable blood donor should be available. The average

blood loss in these craniotomies is between 500 to 1,000 cc. and is to be routinely replaced. Every effort at preventing hemorrhage is the mark of the skilled neurologic surgeon. If these cautions are constantly maintained he finds his problems easier than when he has to fight his way out of a hemorrhagic field.

Hemostatic methods have been discussed in Chapter 1. All of the methods mentioned therein may be necessary in the control of bleeding in cortical incisions and tumor beds. Of particular value are muscle stamps and patient gentle pressure on venous bleeders with moist cotton. Catching vessels in the suction tip and passing the coagulating current through the tip may be time-saving. It should be emphasized that large masses of tissue should not be coagulated or compressed by clips or clamps. Bleeding vessels should be isolated whenever possible.

## PREVENTION OF CORTEX RUPTURES

If there is no struggle on the part of the patient, and he is well oxygenated, it is rare that any surface damage will occur if the dura is properly and rapidly opened. However, if it is obvious that the pressure is so great that rapid cortex exposure is going to result in tissue damages, the simple administration of caffeine sodium benzoate (7½ gr.) intravenously may lower the pressure. Even more effective is 50 cc. of 50 per cent sucrose similarly administered. The ventricle may be tapped and sufficient fluid escape as to permit free cerebral pulsation. In some instances a needle directed into the tumor area will enter a cyst. The escape of 10 to 15 cc. of cystic fluid gives a pressure release comparable to a ventricular drainage. A lumbar puncture with the removal of 20 to 30 cc. of fluid will often allow a dural opening for an immediate cerebral release safely, and can be resorted to as a method for reducing the intracranial pressure in preventing cortical ruptures.

## RADIATION THERAPY

X-ray therapy as an adjunct to the intrinsic tumors of the cerebrum has little or no place. As a matter of fact, if one omits the results in the tumors of the pineal group (which are hopeful), no mention of radiation is necessary. In the metastatic tumors, if decompression is the one neurosurgical effort and the primary growth was previously established as a radiosensitive one, radiation should follow the release of the intracranial pressure. Where there is extensive generalized body metastasis, neither decompression nor radiation is indicated.

## CONCLUSION

It is to be borne in mind that the intrinsic tumors of the cerebral hemispheres are the brain cancers. They constitute less than 50 per cent of the neurosurgeon's tumor problems above the tentorium. The operative hazards of the hemispheric growths are greater than those of cancer elsewhere in the body, but the temporary relief is just as effective and the percentage of "cures" slightly higher. With the life histories of many tumors well written, one is able not only to know of this accurate location, but also to foretell the tumor character. However, not until the craniotomy and tumor exposure is positive confirmation possible. What the surgeon does with his prize and for his patient will depend on his knowledge of the existing pathology, his ability as a technician, and his judgment as a surgeon. At all times the patient's welfare is to be kept uppermost in the surgeon's mind. If a positive permanent cure is not to be effected, he should compare the handicaps of leaving his patient more burdensome on his family and society as the result of radical surgery with palliative efforts which in certain intrinsic brain groups

may result in many years' relief. Microscopic studies and not gross observations are the only basis for an accurate scientific prognosis, and it is well that the surgeon be fully informed of these studies before his final opinion is rendered to the patient.

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# 11

# Tumors of Hypophyseal Region

## Winchell McK. Craig, M.D.

Tumors of the hypophyseal region lie in close proximity to or involve the optic nerves, optic chiasm, pituitary gland, or vessels of the circle of Willis. Thus it is apparent that the symptomatology can be quite complicated and the therapeutic problems quite involved.

Lesions of the hypophyseal region produce two distinct types of symptoms. First, they compress the optic chiasm and nerves, producing visual disturbance as a result of changes in the perimetric fields, of optic atrophy, or of both; secondly, they cause glandular or endocrine symptoms due to decreased or abnormal function of the pituitary gland.

In reviewing a large series of hypophyseal lesions which have been observed and treated at The Mayo Clinic, it is astounding to note the number of patients who are not seen until after irreparable damage to the optic nerves and optic chiasm has occurred, and pituitary dysfunction has become permanent because of pressure and atrophy of the glandular structures. Too frequently the patients, particularly boys and girls during their school years, have suffered from visual disturbances over long periods and except for a change of glasses nothing is done until optic atrophy develops. When finally the diagnosis of a hypophyseal lesion is made a successful surgical procedure is carried out, but it comes too late for restoration of normal vision. Every boy or girl or man or woman who complains of blurring of vision or inability to see, and for whom other treatments fail, should be suspected of having a lesion about the hypophysis. In any case involving a woman, after adolescence, in which amenorrhea associated with visual disturbance develops for no apparent cause, a lesion about the hypophysis should be suspected. Any man who loses in vigor and vision should be examined for hypophyseal lesion.

In reviewing the series the author has also been impressed with the fact that operations performed early in the development of hypophyseal lesions which can be removed have been followed by return of vision and in young women not only has the vision been restored but normal menstruation and subsequent pregnancies have been made possible.

## ANATOMY

According to Rasmussen the hypophysis is a composite organ attached by a slender stalk to the brain just posterior to the optic chiasm. The enlarged part occupies the sella turcica (hypophyseal fossa)—a deep dural-lined depression in the sphenoid bone just above and posterior to the sphenoid sinus The main body measures about 13 mm. transversely, 10 mm. anteroposteriorly, and 6 mm. vertically, but is subject to considerable variation in both size and shape The stalk is from 5 to 10 mm. long.

The hypophysis or pituitary gland is

made up of both a neural and a glandular portion. The neural portion is derived from a downgrowth of the floor of the third ventricle of the brain, and the glandular portion from an upgrowth of epithelium from the roof of the mouth, known as Rathke's pouch. The lower portion of this buccal epithelium elongates and becomes attenuated and solid, while the upper end expands, comes in contact with the anterior surface of the neural portion, and retains its cavity till after birth and to some extent even throughout life. In most adults (human) this lumen is represented by a variable number of narrow clefts or cyst-like cavities usually containing colloid or other fluid materials and cellular débris; these form the region of the so-called craniopharyngiomas or the Rathke's pouch cysts, the Rathke's cleft cysts, or hypophyseal-stalk tumors. That portion of the hypophysis derived from the buccal epithelium is known as the adenohypophysis and that from the brain as the neurohypophysis, the former developing into the anterior lobe and the latter into the posterior lobe of the pituitary gland.

While there is a normal difference in size for the hypophysis, women have a larger hypophysis than men by about 15 per cent. The weight of the hypophysis shows a significant positive correlation with stature, the larger individuals ' having larger hypophyses. Negroes have a slightly larger hypophysis than do whites. The hypophysis normally occupies the cavity within the sella turcica which is lined by dura, the circular fold of which around the main body of the gland forms the diaphragma sellae with an ample foramen through which the infundibulm (or stalk) passes.

Microscopically there are three types of cells in the anterior lobe. Chromophobes (so-called because of their poor staining qualities) are the most numerous, averaging 50 per cent in men and 52 per cent in women, but they vary from 33 to 74 per cent of all the cells. Eosinophils, being indeterminate in number, constitute about 37 per cent in men and 43 per cent in women. The basophils are the least numerous and amount to about 11 per cent of the cells in men and 6 to 7 per cent in women.

The blood supply of the hypophysis consists of one and occasionally two small inferior hypophyseal arteries from each internal carotid artery which traverse the cavernous sinuses. course in the dura along the groove between the two main lobes, and anastomose at the inferior pole, thus forming almost a complete arterial circle in the frontal plane from which branches spread out in the capsule, mostly of the posterior and inferior surfaces of the gland. The hypophysis is innervated by a few hundred unmyelinated sympathetic nerve fibers from the carotid plexus which extend to the anterior lobe by following the blood vessels. It is supposed that they are vasomotor in action.

The hypophyseal region is surrounded by an anastomosing system of vessels known as the circle of Willis which is composed of the intracranial portion of the carotid arteries and branches and the basilar artery and branches. This circle is formed in such a manner that anteriorly the two anterocerebral branches of the internal carotid are connected by an anterior communicating artery and posteriorly each carotid joins the ipsilateral posterior cerebral artery by a posterior communicating artery. In the majority of brains the circle is well formed, but occasionally the congenital absence of one of the communicating arteries occurs and a wide range of variations without clinical effect has been noted. However, the anterior cerebral and anterior communicating arteries, because of their close proximity to the optic chiasm and optic nerves, may cause pressure symptoms (Fig. 89). Shelden has pointed out that pressure exerted by an expanding pituitary tumor forces the optic nerves and chiasm

upward against the vessels and subjects them to the damaging effects of continued arterial pulsations. This has been shown by Kernohan, who in his postmortem studies demonstrated a distinct groove on the superior surface of the optic chiasm which

terior-lobe tissue will prevent noticeable stunting and sometimes accessory hypophyseal tissue may be present along the craniopharyngeal duct. Necrosis or atrophy of the anterior lobe in later life is usually followed by hypophyseal cachexia or Sim-
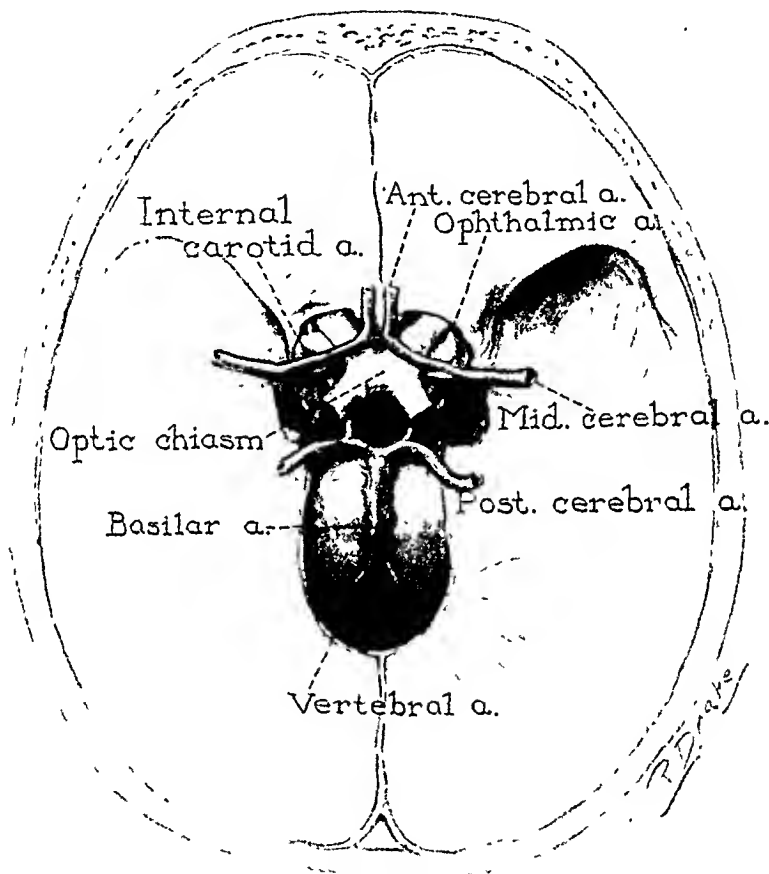


FIG. 89. Relation between circle of Willis, optic chiasm, and optic nerves.

represented the site of local destruction produced by one of these vessels.

## HYPOPHYSEAL LESIONS

Hypophyseal lesions developing early in life result in dwarfism and various degrees of infantilism, depending upon the amount and destruction of the anterior lobe. A small amount of normally functioning an-

monds' disease (emaciation, asthenia, premature senility, apathy, loss of hair and teeth, subnormal metabolism and blood pressure, and loss of libido). Common lesions affecting the hypophysis are those associated with puerperal sepsis, emboli, thrombi, aneurysm, tumors, cysts, tuberculosis, and syphilis. Metastatic lesions are very uncommon. Destruction of the pos-

terior lobe gives rise to diabetes insipidus, failure in temperature regulation, and somnolence.

The hypophyseal lesions which occur most frequently are hypophyseal adenomas, craniopharyngiomas, suprasellar meningiomas, aneurysms, gliomas of the optic chiasm, chiasmal arachnoiditis, and cholesteatomas and chordomas

place The optic chiasm is located on the floor of the skull, just anterior to the stalk of the pituitary body and between the two internal carotid arteries (Fig. 90) The optic nerves anterior to the chiasm contain fibers from the entire homolateral retina and a redistribution of those fibers takes place at the chiasm The fibers from the left half of the right retina and from the
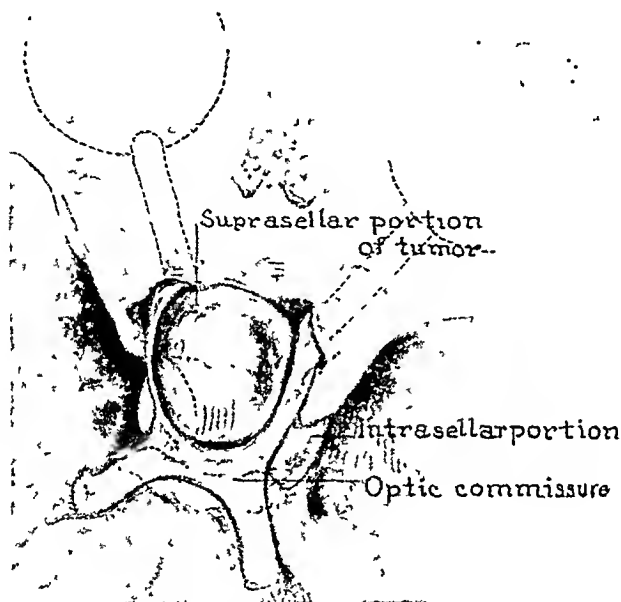


FIG. 90. Relation between optic chiasm, optic nerves, and pituitary tumor.

### OPTIC TRACT AND CHIASM

In view of the fact that visual disturbance comprises the most important symptom of hypophyseal lesions, the mechanism should be considered. Pressure upon the optic nerve and optic chiasm produces changes in the field of vision as well as optic atrophy. The optic nerves extend through the orbit and optic foramen to the optic chiasm. The optic chiasm and a short expanse of the nerve lie superior to the hypophysis At the optic chiasm the optic nerves of the two sides are joined together and a partial decussation of fibers takes

right half of the left retina—that is, from the nasal half of each retina—cross to the opposite sides. The macular fibers cross in the posterior portion of the chiasm where they are exposed to pressure from pituitary tumors

The close proximity of the optic chiasm to the hypophysis makes it evident that any hypophyseal lesions would affect the vision, and it is upon this assumption that the surgical treatment of hypophyseal lesions is based It has become an accepted practice among neurologic surgeons that the criterion for operation is evidence of

compression of the optic nerves or optic chiasm producing visual symptoms. Lesions involving one optic nerve produce blindness of the corresponding eye. Lesions occurring between the optic nerves and compressing the optic chiasm backward compress the crossing fibers which supply the nasal half of each retina and thus produce the classic ophthalmologic picture of bitemporal hemianopia (Fig. 91). Bizarre types of fields are produced by uneven or unequal pressure upon one or both optic nerves or on the optic chiasm. According to Lillie, the

ary optic atrophy in three cases. In not a single case were the fundi normal. According to Deery, who reviewed 47 cases of cysts of the craniopharyngeal pouch, the combined initial complaint was failing vision and frontal headache, except in three cases. It was interesting to note also that in his series the average duration of symptoms was two years. The story of gradual dimness of vision with or without headache was invariably accredited to eyestrain, and glasses had been used Out of 47 cases, 41 were studied for field defects, and bitem-
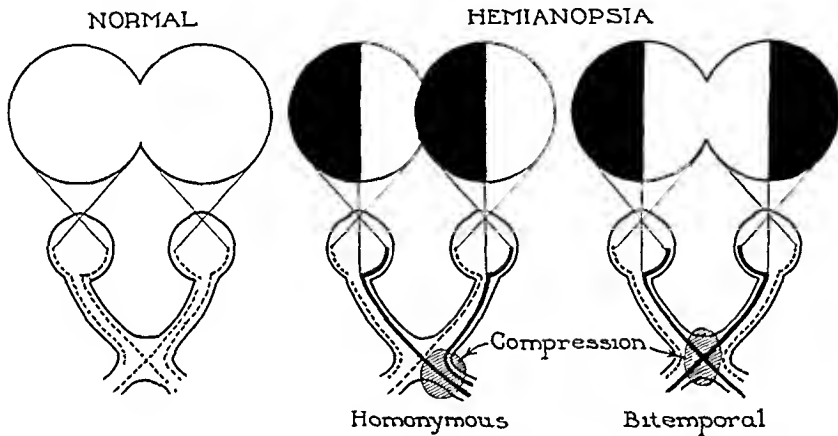


FIG 91. Production of homonymous and bitemporal hemianopia by lesions about optic chiasm

ocular changes produced by pituitary tumors consist of (1) lowered central visual acuity, (2) pale optic disks, and (3) bitemporal, homonymous, scotomatous, or peripheral-field defects. The history of the visual disturbance discloses definite progressive loss of vision with fluctuations in one or both eyes. Glasses, as a rule, are of no aid in increasing the visual acuity

Deery, in his review of 170 cases of pituitary adenomas (proved by operation), found that bitemporal hemianopia occurred in 45 cases, homonymous hemianopia in five cases, no field defects in four cases, primary optic atrophy in 47 cases, choking of the disk alone in four cases, and second-

poral hemianopia was found in 15; temporal hemianopia in one eye with blindness in the other, in 11 homonymous hemianopia, in 9 (right in 4, left in 5); blindness in one eye; nasal defect in the other, in one. The five cases without field defects were early ones, in which there was very little pallor of one or both nerve heads, but enough visual trouble or headache to cause the patient to seek admission. In 36 cases there was primary optic atrophy, in eight there were choked disks, and in three the fundi appeared fairly normal. Aneurysms which may produce hypophyseal symptoms, particularly if they develop slowly and in the midline, are occasionally found

FIG. 92. (*Top*) Normal sella turcica associated with bitemporal hemianopia. At operation a small suprasellar cystic tumor was removed.

FIG. 93. (*Bottom*) Enlarged sella turcica with symmetrical erosion produced by an intrasellar pituitary tumor.

(Fig. 92). Expanding lesions within the sella would naturally show erosion of the anterior or posterior clinoid processes or of both. The usual picture of hypophyseal adenomas is that of a ballooned sella turcica (Fig. 93), without evidence of calcification. In this respect only one other condition may produce confusing changes in the bony contour of the sella turcica. Increased intracranial pressure, particularly that produced by cerebellar lesions, may cause an enlargement of the sella turcica, the roentgenologic aspect of which may simulate an intrasellar lesion. Aneurysms are much less prone to produce symmetrical erosion of bone, although there are cases on record in which the erosion of the sella turcica by an aneurysm could not be differentiated from other intrasellar lesions. Calcification of the walls of aneurysms is characteristic (Fig. 94, *a* and *b*). Suprasellar meningiomas usually show a thickening of the bone in the region of the anterior clinoid processes, although they may show some intrasellar involvement. Craniopharyngiomas have a characteristic picture of an enlarged sella or calcification in the walls of the cyst (Fig. 95, *a* and *b*). Calcified areas within the sella usually indicate a craniopharyngioma. Malignant tumors of the hypophysis and sphenoid sinus produce destruction of the bone (Fig. 96).

## PITUITARY ADENOMAS

In the anterior lobe adenomas are unexpectedly frequent. Costello, in examining sections from 1,000 routine cases, without suspected hypophyseal involvement, found adenomas in 22 per cent. These occurred most frequently in the sixth decade.

Hypophyseal adenomas are of four types; chromophobe, eosinophile, basophilic, and mixed, depending upon the predominant type of cell. Chromophobe adenomas prevail and may become several centimeters in diameter. Basophilic adenomas are the least frequent and are small.

at operation when a pituitary adenoma is suspected. In Deery's three cases primary optic atrophy with bitemporal hemianopia was found.

## ROENTGENOLOGIC DIAGNOSIS

The roentgenologic examination of the head is extremely important in all cases in which hypophyseal lesions are suspected

Chromophobe adenomas give rise to symptoms largely because of pressure on the remainder of the hypophysis or because of its displacement or actual destruction, and acromegalia which includes overgrowth of connective tissue and bone, with the resulting enlargement of the hands, feet, jaw, lip, and so forth Basophilic adenomas produce
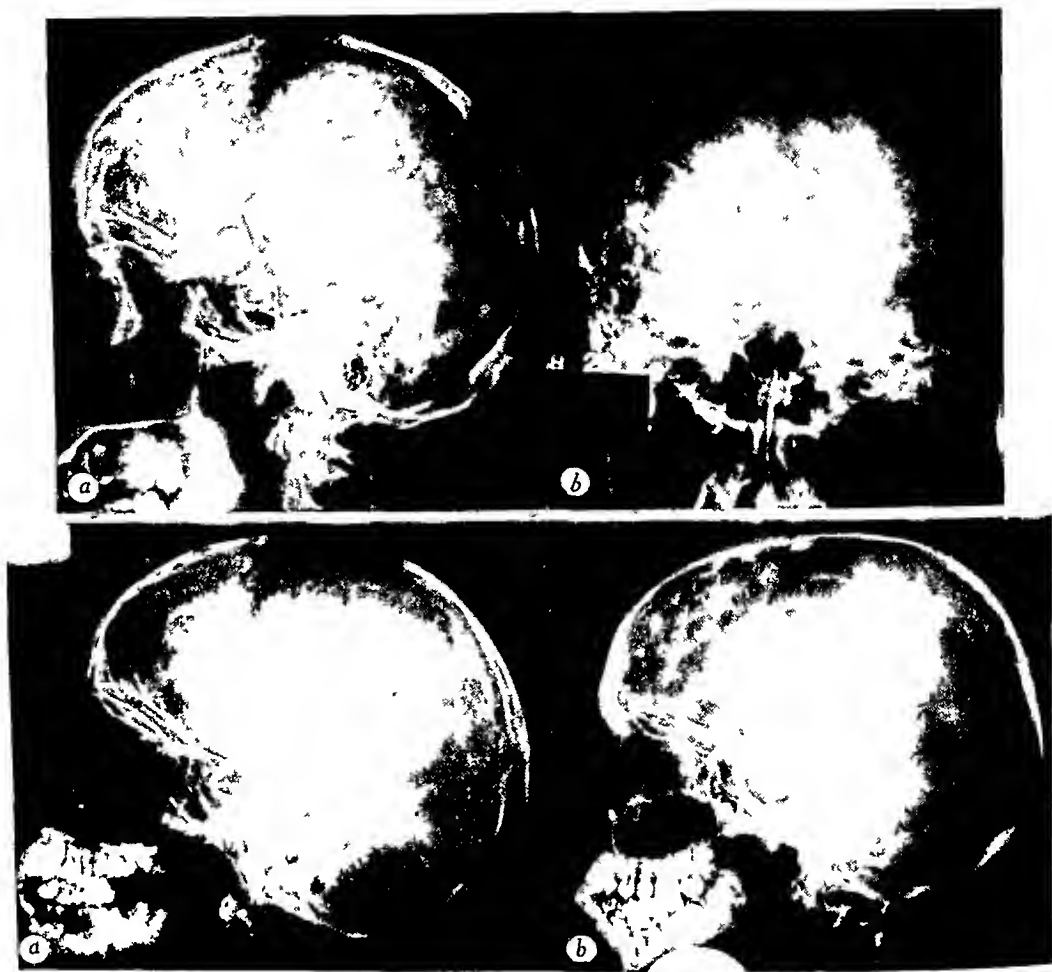


FIG 94 (*Top*) Large calcified intracerebral aneurysm in a case with a history of generalized convulsions for 13 or 14 years and of constant headache and blurring of vision for 10 years. (a) Lateral view; (b) anteroposterior view.
FIG 95. (*Bottom*) (a) and (b) Enlarged sella turcica with craniopharyngioma

because of encroachment upon neighboring structures of the brain such as the optic chiasm. The eosinophile adenomas produce hyperpituitarism consisting in the preadolescent age of delayed union of the epiphyses and gigantism, and in postadolescence of a symptom complex known as a pluriglandular syndrome which has been referred to as the Cushing syndrome, and which consists of sudden adiposity, atrophic striae on the abdominal wall, hirsutism, sexual abnormalities, elevated blood pressure, glycosuria or lowered sugar tolerance, osteoporosis, dusky or florid face,

and bruising easily. Mixed adenomas constitute at least 10 per cent of all hypophyseal adenomas. The clinical symptoms depend upon the predominance of the type of cell.

Some of the more malignant chromophobe adenomas that break through the capsule and invade adjacent structures differ from the usual hypophyseal adenomas. These have been classified as adenocarcinoma. True sarcomas are rarely found in



FIG. 96. Enlarged sella turcica with marked erosion characteristic of adenocarcinoma of pituitary.

the hypophysis. Teratomas and psammomas have been described, as have endotheliomas invading the hypophysis. Cystic tumors lined with simple columnar ciliated epithelium are usually called "craniopharyngiomas" and "suprasellar cysts." These are referred to later.

The chromophobe type of adenoma is the most common tumor of the hypophysis as well as the one most amenable to surgical treatment.

The clinical features produced by the chromophobe tumor represent a true compression syndrome, in contrast to the symptoms of the eosinophile and basophilic adenomas which result from a specific hypersecretion.

The three structures usually involved by the pressure of an expanding primary intrasellar neoplasm are the normal glandular tissue of the hypophysis, the bony confines of the sella turcica, and the optic chiasm.

Growth of the adenoma within the sella turcica gradually compresses the remaining glandular tissue and produces a slowly progressive reduction in pituitary function.

Menstrual irregularity or amenorrhea probably is the most common initial symptom, and may antedate by many years other evidence of hypopituitarism. Loss of libido and potentia is frequently the earliest feature of pituitary dysfunction observed in men.

Long-standing compression of the remaining glandular substance results in the classic pituitary syndrome. The essential features of marked pituitary dysfunction are excess weight; smooth, dry, semi-edematous, pale lemon-yellow skin; scanty body hair with an abnormal velvet-like texture; a low basal metabolic rate; and a subnormal blood pressure. Children who have typical Fröhlich's syndrome present, in addition to these symptoms, a dwarfish stature and a lack of development of the secondary sex characteristics.

Headache is frequently a distressing early symptom. It is usually localized to the inferior frontal region near the midline on one or both sides. This type of headache differs in many respects from that due to other brain tumors. It is not due to an increase in intracranial pressure, but results from stretching of the dural roof or diaphragma sellae. No doubt the many variations in the severity and duration of the headache may be traced to anatomic differences in this portion of the dura mater.

Every chromophobe adenoma of the pituitary will produce visual disturbance provided it attains sufficient size. However, the character of the visual defect depends

more upon the location of the optic chiasm and direction of growth of the tumor than upon its actual proportions. Other factors, such as the extent of cystic degeneration of the lesion and the occurrence of hemorrhage into the tumor, play an important but secondary rôle in producing the loss of vision.

The effect of hypophyseal lesions upon the optic chiasm has already been discussed, and the cause for bitemporal hemianopia as well as for bizarre field changes has been pointed out.

A tumor which presents well anterior to the optic chiasm between the optic nerves produces a prechiasmal type of visual-field defect, the essential feature of which is an early loss of central vision. As the tumor enlarges the optic chiasm itself becomes affected. The result is the usual bitemporal type of hemianopia plus the original central or cecocentral scotoma. The late result of such a process is usually amaurosis in one eye and temporal scotoma in the other.

A chromophobe tumor which presents posterior to the optic chiasm between the optic tracts may produce only bitemporal hemianopia provided the lesion remains adjacent to the chiasm with the bulk of the growth essentially in the midline. However, irregular extension may easily produce optic-tract (that is, retrochiasm) pressure and a homonymous type of hemianopia.

Shelden has called attention to the fact that the two outstanding funduscopic features produced by pituitary tumors are pallor and loss of substance of the optic nerve head. The pallor precedes the loss of substance. Papilledema associated with a pituitary tumor does occasionally occur, and when present usually signifies a very large lesion and a grave prognosis. It should be borne in mind that papilledema never develops once primary optic atrophy has appeared, even though subsequent enlargement of a tumor produces a marked increase in intracranial pressure.

The prospect of visual improvement following operation depends more upon the degree of pallor and loss of substance of the optic disk than upon the extent of the visual-field defect.

The treatment discussed later is predominantly surgical although roentgen therapy has been used and the results vary with the degree of damage to the neighboring structures. Permanent restoration of visual and glandular function has resulted from operation carried out early in the development of symptoms (Fig. 97).

### CRANIOPHARYNGIOMAS (TUMORS OF HYPOPHYSEAL DUCT OR OF RATHKE'S CLEFT, AND ADAMANTINOMAS)

Rathke's pouch in the terms of the anatomist is an invagination from the roof of the primitive oral cavity. In the process of development it becomes constricted off and a sac is formed with a narrow stalk. The sac eventually closes and the stalk, originally connected with the mouth, usually disappears. This stalk in some cases persists, as does the thyroglossal duct, and from the epithelial rests the stalk tumors have their origin.

The original Rathke's pouch becomes converted into a solid structure, the pars anterior or the glandular lobe of the hypophysis. However, between the pars anterior and the pars posterior a small cleft persists which is all that remains of the original Rathke's pouch, and from this cleft the tumors arise.

Histologically the tumors have been classified as adamantinoma, anatomically as interpeduncular or supraseller cyst, and embryologically as Rathke's cyst, craniopharyngioma, and tumor of the hypophyseal duct. They may vary greatly in their gross and histologic appearance as well as in their exact situation. However, all instances have in common the development from squamous epithelial cell rests which are remnants of the embryonic hypophyseal

duct, and consequently it appears logical to designate such a growth as a tumor of the hypophyseal duct, hypophyseal stalk, or Rathke's cleft.

ment of the adjacent structures. The capsule is in many instances smooth and white and of sufficient density to tolerate considerable manipulation without tearing;
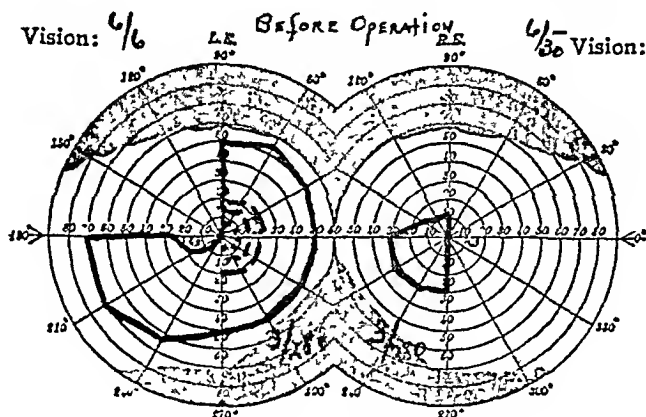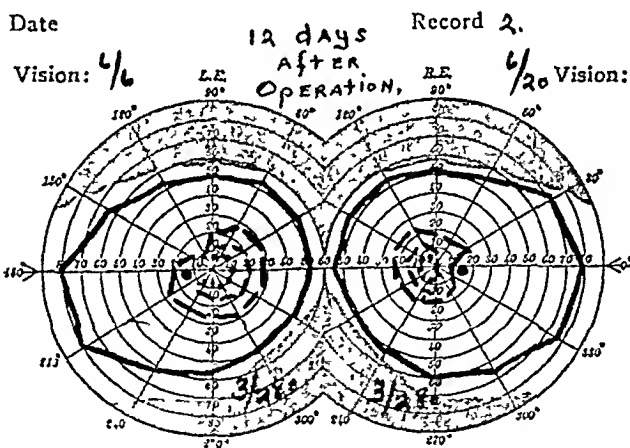


FIG. 97. Perimetric fields in which there was marked pallor of both disks, and the remarkable change 12 days after operation. Twelve years later, fields and fundi were normal *and patient was in excellent health.*

Craniopharyngiomas vary in gross appearance from a small, solid, well-circumscribed, discrete growth to a huge, multilocular cyst producing marked displacement

however, it may be thin and fragile and may have a dark appearance as a result of the color of the contained fluid. If the tumor is of long standing or has developed

with great rapidity, it may infiltrate the surrounding tissue to such an extent that surgical dissection of the lesion from the adjacent structures is impossible (Fig. 98). Although the tumor is generally solid in its early stages it soon undergoes cystic degeneration; the fluid contents of the cyst are usually yellowish, dark brown, or greenish brown, and there often is as much as 2 to 3 ounces (60 to 90 cc.) of this fluid. Gen-

in which the entire tumor became stone-hard, so that it was impossible to section it by routine methods for microscopic studies.

Three types of craniopharyngioma have been recognized: (1) Mucoid epithelial cysts, (2) squamous epitheliomas, and (3) adamantinomas. The mucoid epithelial cysts are lined with ciliated columnar and mucus-secreting cells and are supported by degenerating connective tissue. Squamous



FIG. 98. Cross-section of brain showing difficulty in removing a cyst of Rathke's pouch.

vade the sella and destroy the hypophysis. Teratomas also may arise from the epithelial remnants of the stalk.

The symptoms of craniopharyngiomas do not follow a stereotyped pattern but depend on the size and rate of growth of the tumor as well as on the order in which the adjacent structures are involved.

The exact site of origin of the tumor in relation to the dural roof of the sella turcica has been stressed in determining the developmental sequence of the clinical symptoms. A tumor which develops from epithelial cell rests situated below the diaphragma sellae naturally compresses first the pituitary body and later the diaphragm. Thus it is that signs of pituitary dysfunction may long antedate other symptoms, and such a lesion, because of its anatomic situation, may be considered an epidural growth. In many instances long-standing mild headache may be the result of gradual upward stretching of this portion of the dura.

A tumor arising above the dural roof of the sella turcica has its origin in cell rests situated along the stalk of the infundibulum and the anterior superior aspect of the capsule of the pituitary body. It is within the subarachnoid space and tends to fill the cisterna basalis. Early involvement of the visual pathways and of the hypothalamus is the rule and pituitary dysfunction is not marked, because the lesion is separated from the pituitary body by the diaphragma sellae.

If the tumor originates from rests situated at the point of passage of the stalk through the dural roof, rapid growth of the mass may cause simultaneous functional changes in structures both above and below the diaphragma sellae.

The development of symptoms may diverge from any given pattern by a sudden hemorrhage into a cystic cavity or by a local degenerative process producing a local or diffuse inflammatory process in the suprasellar region.

The symptoms may be the result of pituitary dysfunction, visual disturbance, hypothalamic compression, or increased intracranial pressure associated with hydrocephalus. Generally the initial symptoms are either visual or pituitary, but if the lesion is allowed to progress to a sufficient size the majority of the classic symptoms will be present.

Pituitary involvement results in degrees of dysfunction varying from mild, hypopituitary states to obvious dystrophia adiposogenitalis. The endocrine disturbances are generally evidenced by the Fröhlich type of physical appearance. Love, Shelden and Kernohan found that visual disturbances constituted the most common initial symptom, being present in some form in every case. Progressive dimness of vision was the most common mode of onset; and in most instances (8 of 11 cases) this was the result of gradually developing primary atrophy of the optic nerve. It is noteworthy that in six of these eight cases the defect in the visual field was bitemporal. Homonymous hemianopia occurred in four cases; in two there was associated mild papilledema, and in one there was a well-advanced degree of primary atrophy of the optic nerve. A high degree of choked disk (4 diopters) was noted in only one case, the patient being a girl aged five years. Because of the age of the child the visual fields could not be outlined. In one case there was a history of definite visual hallucinations which had been associated with uncinate attacks.

The treatment of craniopharyngioma is surgical in all cases in which the symptoms have not progressed to the point of complete blindness or physical disability. The mechanical release of the cystic fluid with relief of pressure on the contiguous structures is the only method of relieving the symptoms. As in no other condition, early diagnosis is important before the cystic

growth has had time to produce irreparable damage to the optic nerves and chiasm as well as to the hypothalamus and third ventricle. The removal of the cyst wall is necessary to prevent recurrence but too frequently it is impossible to do much more than aspirate the fluid. One of the earliest diagnoses and best surgical results was accomplished in a boy aged seven years in adults. In 70 to 80 per cent of these cysts there is roentgenologic evidence of calcification above the sella, and the latter, while formed, is not often symmetrically ballooned as in the adenomas. As soon as the diagnosis of parahypophyseal lesion and, if possible, the differential diagnosis between the conditions under discussion are made, the next step is to determine whether or
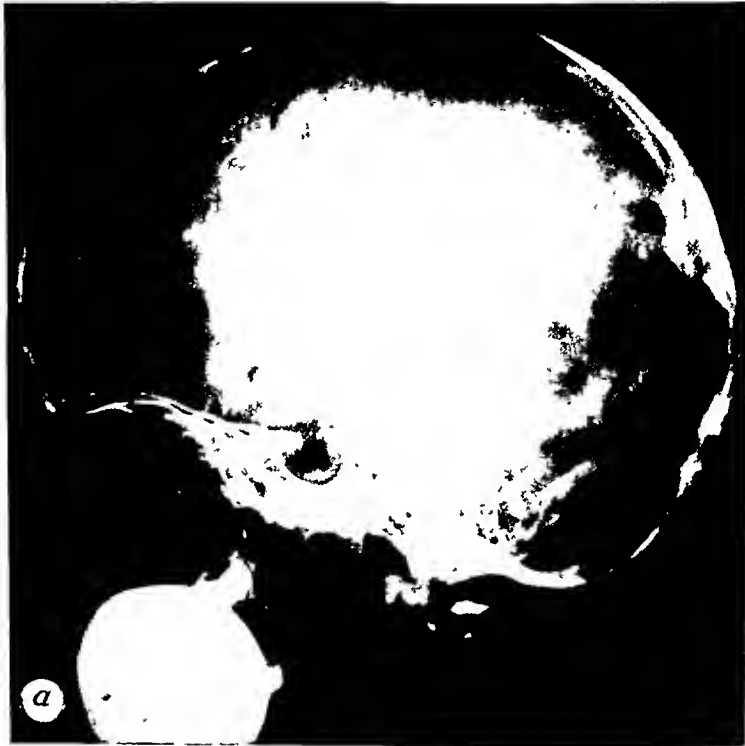
FIG. 99. Erosion of floor of sella turcica and enlargement of sella by a tumor above and partly within it.

whose history was short and consisted of headache together with visual difficulty in the right eye. The diagnosis was made on the basis of the visual field and roentgenographic changes. A complete restoration of vision, relief of headaches, and no evidence of recurrence for five years have followed surgical removal (Figs. 99 and 100).

Although craniopharyngiomas are most frequently seen in children, they do occur not the patient is in need of any form of treatment directed toward the removal of pressure from the optic nerves, the chiasm, or the structures along the base of the brain posterior to the chiasm. The loss of vision from optic atrophy has always been the criterion for surgical intervention. In addition to visual loss, severe headaches, particularly in cases of acromegaly, and symptoms of increased intracranial pres-

sure in adenomas which extend backward and upward also constitute indications for reducing the bulk or for removing the tumor. Glandular manifestations alone, without evidences of pressure on the surrounding structures, are rarely if ever a sufficient reason for surgical intervention.

### PARAHYPOPHYSEAL ANEURYSMS

Lesions in the hypophyseal region include aneurysms of the circle of Willis, of the internal carotid artery, and of the an-

clear and syphilis seems to play a very unimportant part even in young persons. The most likely cause is a congenital defect of the vessel wall involving the muscular coat at the junction with either a larger or a smaller branch. In older persons, unquestionably arteriosclerosis is a factor. When mycotic aneurysms occur, they are more common in the cerebral than in the basilar vessels.

According to McDonald and Korb, who reviewed the postmortem and operative lit-
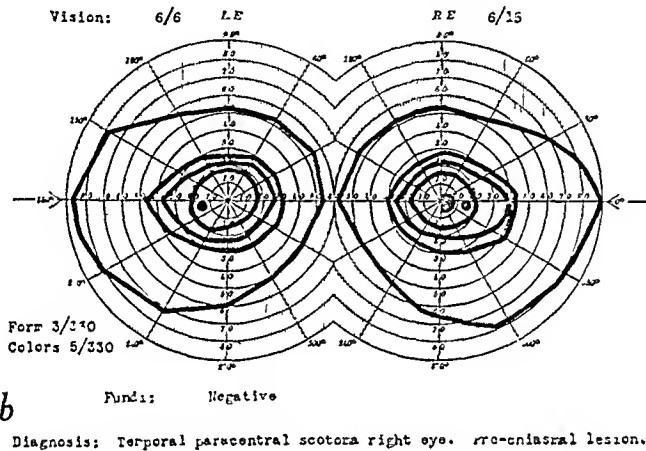


FIG. 100. Visual fields in same case as shown in Fig. 99.

terior and middle cerebral and the posterior communicating vessels. In addition, the ophthalmic artery may produce pressure on the optic nerves and chiasm by means of aneurysmal enlargement.

The clinical history is suggestive, and consists of sudden and intense headache with rigidity of the muscles of the neck, fainting, or unconsciousness. The presence of bloody cerebrospinal fluid is confirmative evidence. Of the focal symptoms, oculomotor paralysis and trigeminal pain in the ophthalmic division are the most constant. Periods of remission, of weeks' and months' duration, help to differentiate this lesion from tumor.

The cause of cerebral aneurysms is not

erature of 1,125 cases of saccular aneurysms, 48 per cent were found to involve the internal carotid or middle cerebral artery, 15 per cent involved the anterior communicating artery, and 28 per cent were posterior to the internal carotid. All ages were represented from a year and a half to 87 years. Of the patients 54 per cent were more than 40 years of age, 35 per cent were between 21 and 40 years of age, and 11 per cent were 20 years of age or less. The sudden rupture of these saccular aneurysms proved to be three times more frequent in the anterior part of the circle of Willis than in the posterior part. The causation has been attributed to (1) mycotic aneurysm from infected emboli, (2) posttraumatic
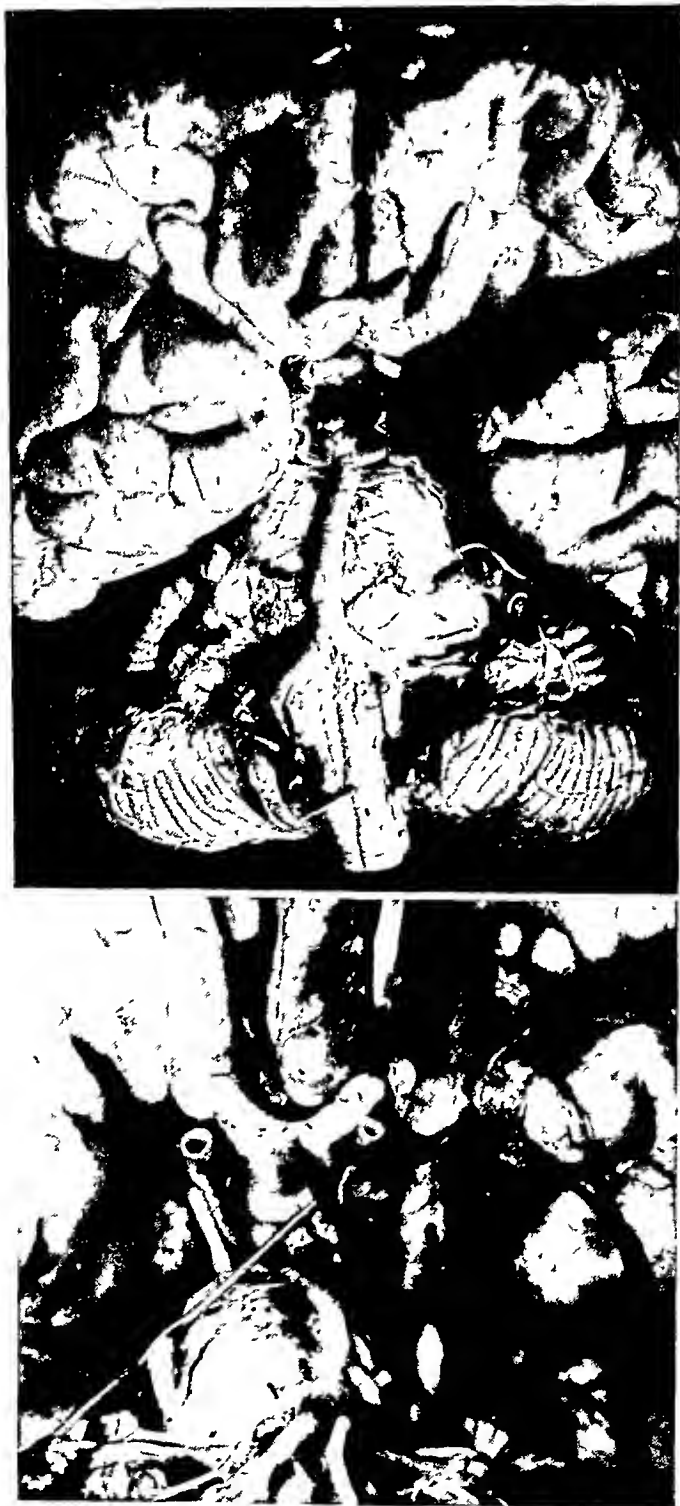
Fig. 101. (*Left*) Aneurysm of cerebral artery in region of optic chiasm which had produced few symptoms, patient dying of coronary thrombosis.
Fig. 102. (*Right*) Aneurysm of left internal carotid artery in a man, aged 20 years, with sudden collapse and headache following exercise without evidence of neighborhood signs.

fracture of the base of the skull, (3) aneurysm due to syphilis, (4) aneurysm associated with and probably due to atheroma, and (5) aneurysm resulting from congenital defect.

According to Forbus, the aneurysms of the miliary type always occupy the angle formed by a branching artery, and the defect in the arterial wall is always located at the bifurcation and at a point where miliary aneurysm occurs characteristically (Fig. 101). The defect of the muscularis constitutes a decreased resistance.

It has been proved that miliary aneu-

tive Kernig's sign of sudden onset, if not immediately fatal, should always be suggestive of intracranial aneurysm. In addition to the oculomotor paralysis the fourth cranial nerve and the ophthalmic division of the fifth are frequently involved. Among the ocular phenomena of hypophyseal aneurysms may be included field defects, ptosis, strabismus, diplopia, proptosis, edema of the eyelids, and venous engorgement from pressure on the cavernous sinus.

The gradual onset of the symptoms is characteristic of tumors but likelihood of an aneurysm should be kept in mind A



Fig. 103. Bilateral aneurysmal enlargements of ophthalmic artery producing bizarre perimetric fields, improved by unroofing optic canal.

rysms of superficial cerebral arteries occur quite independently of any inflammatory process, arteriosclerosis, or external trauma, and that these aneurysms as such are not congenital malformations.

Most of the intracranial aneurysms produce symptoms of ophthalmoplegic migraine which consist of recurring headache during which cranial-nerve palsies of a transitory nature occur. These symptoms are due to intermittent enlargement of the sac or leakage. Blood in the subarachnoid space may produce sudden severe headache associated with pain in the shoulder, arms, back and legs. Following this, coma, rigidity of the neck, hemiplegia, delirium, and mental confusion may occur. Bloody spinal fluid is diagnostic. Intense headache, rigidity of the neck, ocular palsies, and a positive

tumor may cause pressure on the third, fourth, and fifth cranial nerves, often with field defects, but the patient never exhibits the signs of leakage or rupture, the intense headache and the stiff neck, with blood in the cerebrospinal fluid.

The symptoms of aneurysms about the hypophysis vary with their location (Fig. 102). The internal carotid artery, after entering the skull, turns forward and runs through the cavernous sinus before turning upward and penetrating the dura just behind the fourth and sixth nerves, and anesthesia in the distribution of the trigeminal nerve makes the lesion easily recognizable. An aneurysm of the internal carotid artery at its junction with the ophthalmic artery may produce all the clinical symptoms of hypophyseal lesions (Fig. 103). Aneurysms

at the junction of the internal carotid artery and the posterior communicating artery may cause palsy of the third nerve as a diagnostic indication or may produce symptoms indistinguishable from those of hypophyseal lesions.

The treatment of these intracranial aneurysms consists of the intracranial application of muscle, the intracranial application of silver clips, or the intracranial removal of the saccular aneurysm and ligation of the internal carotid artery if after compression for 20 minutes no untoward symptoms are produced. Following ligation of the internal carotid artery, thrombosis occurs up to a point just below its bifurcation into the anterior and middle cerebral branches Circulation in the middle cerebral branch is maintained by the anterior part of the circle of Willis through the bifurcation There is a definite risk in patients more than 50 years of age because of arteriosclerosis and embolism of the middle cerebral artery.

Arteriography is helpful in making the diagnosis, but is not necessary It is possible to localize intracranial saccular aneurysms accurately by clinical means alone when they occur in the cavernous portion of the internal carotid artery, giving rise essentially to palsy of the third nerve with evidence of involvement of the first or first and second divisions of the fifth nerve and frequently the fourth, sixth, and motor division of the fifth cranial nerve as well. Palsy of the third nerve alone is not of localizing value as it may occur with aneurysms arising from any of the arteries at the base of the brain Clinical evidence of compression of one optic nerve or the optic chiasm, particularly if accompanied by roentgenologic evidence of unilateral erosion of the sella turcica or of the clinoid processes or occurrence of linear shadows of calcification at the base of the brain, should suggest the possibility of unruptured intracranial aneurysm. Arteriography

with contrast media at the present time offers the only accurate means of localization of intracranial saccular aneurysms. A normal arteriogram does not exclude the presence of an intracranial saccular aneurysm since partial or complete thrombosis may have occurred, thus obscuring the picture.

Selection of patients for surgical treatment depends upon the demonstration of an adequate collateral circulation through the circle of Willis, upon the position of the aneurysm, and upon the age of the patient and the condition of the peripheral vessels. Intracranial exploration with clipping of the neck of the aneurysm, placing a collar of muscle or fascia about the aneurysm or removal of the aneurysm, will probably be performed more frequently in the future but can be expected to succeed only in those patients who have aneurysms which are accessible and which have been accurately localized previously.

### GLIOMA OF OPTIC CHIASM

**Primary Tumors of Optic Nerves or Chiasm.** These usually produce a very rapid loss of vision with bizarre visual-field changes often associated with enlargement of the optic foramina.

Primary tumor (glioma) of the optic chiasm and nerves is discussed elsewhere and is mentioned here only to complete the differential diagnostic discussion

Tumors of the optic nerve and chiasm, globular tumors, almost always gliomas, are found occasionally involving one or both optic nerves alone or with the chiasm They are mostly seen in children, and the diagnosis is speculative unless by the roentgenogram one finds the optic foramina enlarged and the anterior section of the sella turcica expanded forward. Primary optic atrophy and field defects are inevitably associated with loss of visual acuity. These tumors do not lend themselves to surgical treatment.

Suprasellar Meningiomas. Suprasellar meningiomas or meningiomas of the tuberculum sellae are rare but produce a characteristic syndrome consisting of bitemporal defect of the visual fields and primary optic atrophy in middle-aged patients in whom the sella turcica may be normal and there are no signs of involvement of the hypophysis or hypothalamus. These tumors in the early stages of development can be removed surgically and the improvement in vision may be extraordinary. These meningiomas probably arise from arachnoidal granulation in the anterior communicating branch of the cavernous sinus.

Suprasellar Cholesteatomas. Suprasellar cholesteatomas are also rare but may be diagnosed preoperatively because of the syndrome of bitemporal hemianopia and a slowly progressive optic atrophy occurring in young people, associated with a normal sella turcica, enlarged optic foramina, and absence of pituitary changes. Unfortunately, patients with this type of lesion are in such good general health that the failing vision is treated with a change of glasses until optic atrophy is almost complete. This type of tumor, being avascular, is usually easily removed and the restoration of vision may be greater than the amount of optic atrophy would warrant.

Chordomas. Chordomas occur but rarely to confuse the diagnosis of hypophyseal lesions. About 1 cm. posterior to the dorsum sellae on the clivus a small structure called the ecchordosis physaliphora has been proved to be a remnant of the notochord. From this may arise a tumor which has been called "chordoma." Projecting forward such tumors can produce visual and glandular symptoms, but usually involvement of other cranial nerves or pressure on the cerebral peduncles identifies this type of tumor as being more extensive than the lesion confined to the . region of the sella turcica, optic chiasm, and pituitary gland.

Chiasmal Arachnoiditis. Nonne used the term "pseudotumor" to designate a circumscribed collection of subarachnoid fluid and also referred to it as meningitis circumscripta or arachnoiditis. These pseudotumors are frequently seen in the suprasellar region and except for the pneumogram, which may portray a filling defect of the cisterna chiasmatis, the verification of this lesion cannot be made until the lesion is exposed on the operating table. Producing bitemporal hemianopia, enlargement of the sella turcica, primary optic atrophy, and signs of hypophyseal dysfunction, pseudotumors may so simulate a solid tumor of hypophyseal origin that they are indistinguishable until seen at operation.

The causation of "cisternal arachnoiditis" is obscure. A focus of infection, such as in the ethmoid, has been suggested, but cases have been reported in which the condition developed insidiously without any evident causative factor. The diagnosis must finally be verified by the operative findings, thickening of the arachnoid with adhesions, and a circumscribed collection of fluid in the cisterna chiasmatis.

In addition to the increased amount of fluid in the cisterna chiasmatis the optic nerves are sometimes found to be surrounded and constricted by the thickened pia arachnoid and it is sometimes necessary to free the constricting membranes from the optic chiasm and optic nerves.

From the standpoint of diagnosis the visual phenomena consisting of loss of visual acuity, field distortion, and the concentric contraction of vision comprise the main symptoms. Field defects may be typical hemianopia, either bitemporal or homonymous, or may be regular and atypical.

## TREATMENT OF HYPOPHYSEAL LESIONS

As soon as a diagnosis of hypophyseal lesion has been made, the most effective type of treatment should be decided upon.

If the lesion is more or less indeterminate and operation is indicated as a diagnostic as well as a therapeutic measure (as is so often the case in chiasmal arachnoiditis) and the condition of the patient warrants it, then little choice remains. However, when the diagnosis is clearly that of an adenoma of the pituitary gland roentgen therapy can be considered. However, craniopharyngiomas, aneurysms, and other lesions producing pressure on the optic chiasm and nerves require surgical inter-



FIG. 104. Healed wound of a right transfrontal craniotomy 12 days after operation.

vention, not being radiosensitive, as the vision is threatened and relief of pressure is imperative.

Surgical Treatment. In view of the fact that the transsphenoidal operation. which enjoyed such popularity a decade ago has been practically abandoned because of its associated danger of infection, and because of its inadequacy in removal of tumors, no detailed discussion of it will be given here.

Some form of frontal intracranial exposure of the hypophysis has been adopted by all neurosurgeons. The technical points of the operative approach differ with individual surgeons, but fundamentally all methods of exposure consist in the reflection of an osteoplastic flap placed far enough anteriorly so that the frontal lobe, preferably the right can be easily retracted or elevated and the chiasmal region exposed (Fig. 104). The osteoplastic flap need not be large, as sufficient room is provided by an area which includes only the frontal region. Two forms of skin incision are used by most neurosurgeons. The first, and probably the most popular one, is that shown in the illustration (Fig. 105). A curved incision is made in the scalp, beginning in the midfrontal region just above *the bridge of the nose and extending in the* midline to the hairline, where it begins to curve outward gradually until the posterior limb is just in front of or over the ear. The skin flap is reflected downward until the supra-orbital region is exposed, and an osteoplastic flap is reflected with the base in the temporal region after the insertion of five trephine openings connected with the Gigli saw and reflected independent of the skin flap.

The second or "coronal" incision is made entirely within the hairline and extends upward from above one ear across the vertex and down to above the other ear. The scalp is reflected forward bilaterally, *following which the bone flap can be made* as in the first method. By the coronal incision any visible scar is eliminated since it is eventually covered by hair, but even in the first type of incision the only visible portion is the vertical line in the forehead, and when this is closed with sufficient care there is almost no evidence at the end of six months to a year.

In making the osteoplastic flap it is always necessary to examine the roentgenogram carefully with regard to the outline of the frontal sinus so that the trephine opening in the frontal region can be placed above the sinus on account of the danger of infection. At times the frontal sinus is very high and is unintentionally opened, but if

it is closed with bone wax or a piece of fascia the danger of infection is minimized.

After the osteoplastic flap has been reget the maximal retraction. By cutting the dura low down in this manner the frontal lobe may be retracted with the least
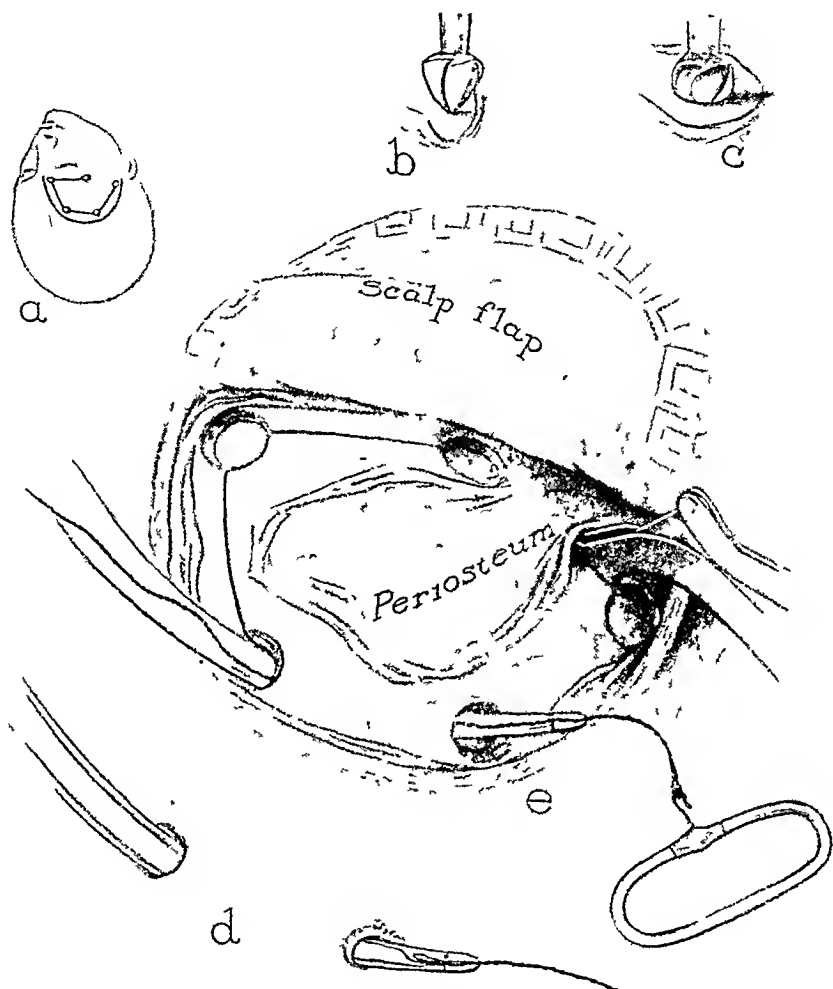


FIG. 105. Right transfrontal craniotomy. (a) Skin incision with outline of bone flap, (b) bone perforator, (c) Hudson drill, (d) dural guide with Gigli saw, (e) reflection of periosteum. Insertion of Gigli saw and method of preparing bone flap.

flected the dura is gently dissected from the inner surface of the skull and the orbital plate down to the sphenoidal ridge where it is attached At the point of attachment an incision is made which is carried forward and then upward in order to

possible injury This is the so-called extradural approach in contrast to the intradural approach, which consists of an incision in the dura without dissecting it from the inner table of the skull and elevating the frontal lobe as is done in the

usual craniotomy. The extradural approach has the advantage that the dura can be used as protection to the cortex of the

which the lesion is predominantly on the left side and the question of exposure is the determining factor. Another situation
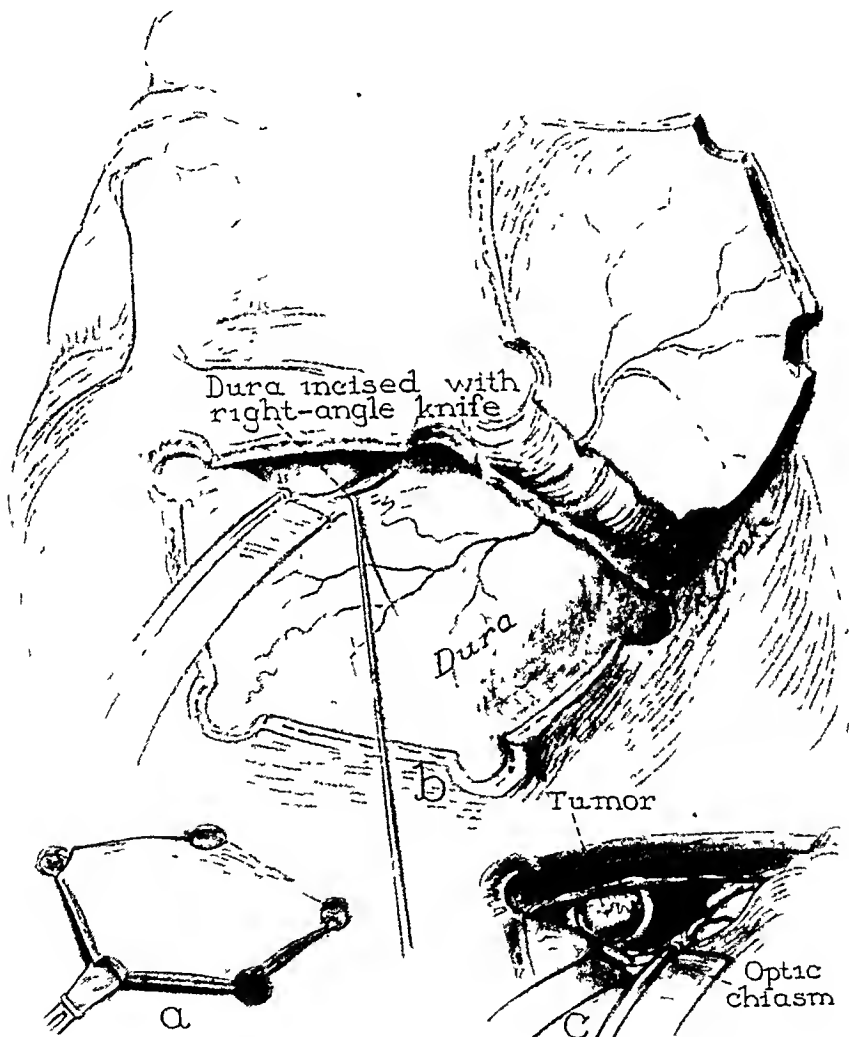


FIG. 106. Transfrontal exposure of optic chiasm: (a) Elevation of bone flap, (b) incision of dura, (c) exposure of pituitary tumor by elevation of right frontal lobe.

brain, allowing it to be retracted with the least possible injury, the only portion of cortex exposed being the small area between the chiasm and the dural incision. A right transfrontal craniotomy is usually advantageous in all cases except those in

in which there might be reason for choosing the left side as an approach to hypophyseal lesions would be in those rare instances in which one optic nerve has to be sacrificed in order to remove the tumor.

Following the incision of the dura along

the sphenoidal ridge there is usually an escape of cerebrospinal fluid in such a quantity that it is unnecessary to collapse the brain further by tapping the ventricle. Using strips of cottonoid to protect the exposed undersurface of the brain a smooth flat spatula or lighted retractor is introduced to retract and elevate the frontal lobe. This procedure brings the right optic nerve into view (Fig. 106). With careful

able, in order to determine whether the tumor is cystic or solid. If the tumor should prove to be an intrasellar aneurysm (Fig. 107), the small opening can be closed with a pledget of muscle. If the tumor proves to be a chromophobe adenoma and is cystic, its liquid contents can be evacuated. This procedure always assists in the subsequent removal of the tumor.

When it has been proved that the tumor
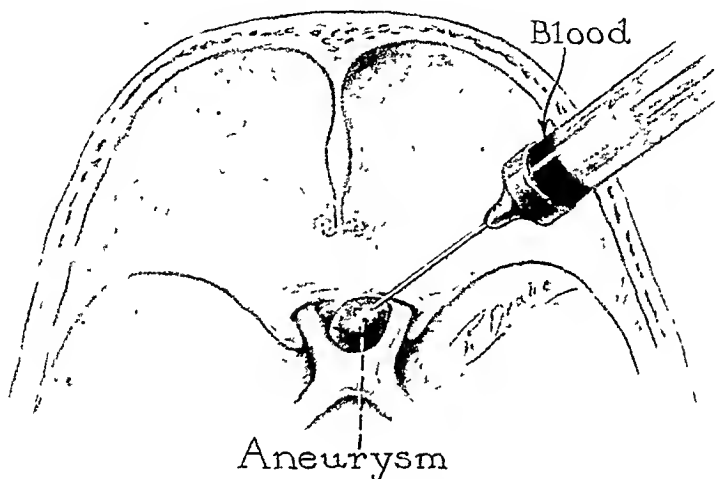


FIG. 107. Intrasellar aneurysm simulating pituitary tumor and method of diagnostic aspiration.

dissection the optic chiasm can be seen, and if one is dealing with an intrasellar or suprasellar lesion this can easily be seen. In the cases in which a pituitary adenoma is found it is recognized as a grayish-red, rounded mass protruding anterior to the optic chiasm. The right optic nerve and the surface of the tumor are covered by arachnoid. Gentle dissection of the arachnoid allows for the exposure of the left optic nerve.

When the lesion has been exposed and the surrounding structures have been identified, the first procedure to be carried out is the insertion of a needle, preferably a spinal-puncture needle of small caliber attached to a syringe. This is always advis-

is not an aneurysm and is a neoplasm, the capsule can be incised (Fig. 108) and the solid portion removed by pituitary forceps or suction. This is the so-called intracapsular enucleation and the capsule of the adenoma can then be gently dissected away from the optic nerves and chiasm and excised or coagulated with an electrosurgical unit. In view of the fact that most pituitary adenomas are solid and their contents vary from soft, degenerating material to a firm, fibrotic type, a complete removal of the tumor is sometimes difficult but it should always be attempted. After intracapsular enucleation has been carried out and the capsule gently dissected away from the surrounding structures, it can sometimes be

removed completely or coagulated, great care being taken that the optic nerves at no time are endangered by coagulation.

When the capsule or adenoma extends laterally into the region of the internal carotid artery, it is often necessary to leave a portion rather than to run the risk of

shown that in 5 per cent of persons the chiasm is far forward near the sulcus chiasmatis of the sphenoid bone. In 4 per cent the optic chiasm is located far posterior over the dorsum sellae. Fortunately, in the great majority of cases the optic chiasm lies immediately over the sella turcica and
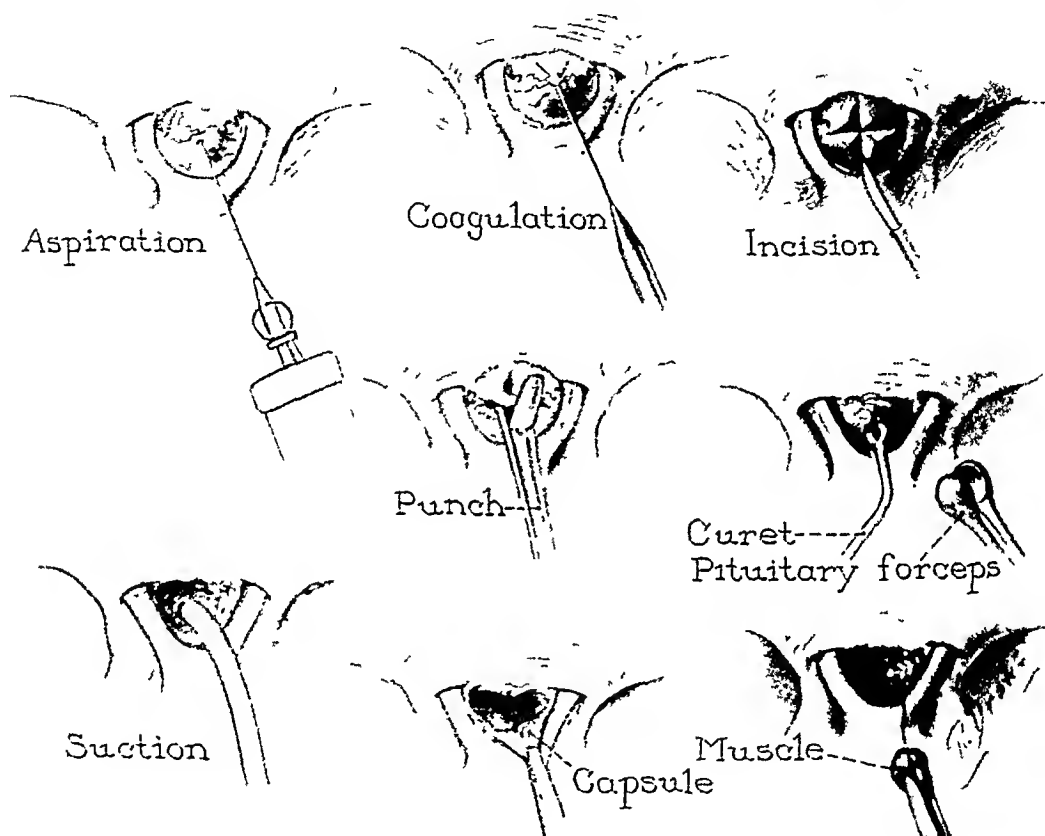


Fig. 108. Stages in dealing with a pituitary tumor at time of operation.

copious hemorrhage from the carotid artery or its branches. Occasionally a tumor is encountered which has projected beyond the sella turcica either laterally or posteriorly. In these cases the intracapsular enucleation should be carried out and as much of the capsule as possible removed.

The fact that the optic chiasm is not constant in its relationship to the sella turcica sometimes affects the ease with which the tumor can be exposed. It has been

the lesions compress it posteriorly, allowing for good operative exposure. In some neurosurgical clinics the procedure is to make encephalograms as a matter of routine diagnosis. Some of these studies have been very interesting but hardly conclusive enough to warrant this additional procedure when a diagnosis of hypophyseal lesion can be made.

After the lesion has been removed the incision in the dura is not closed as the dura
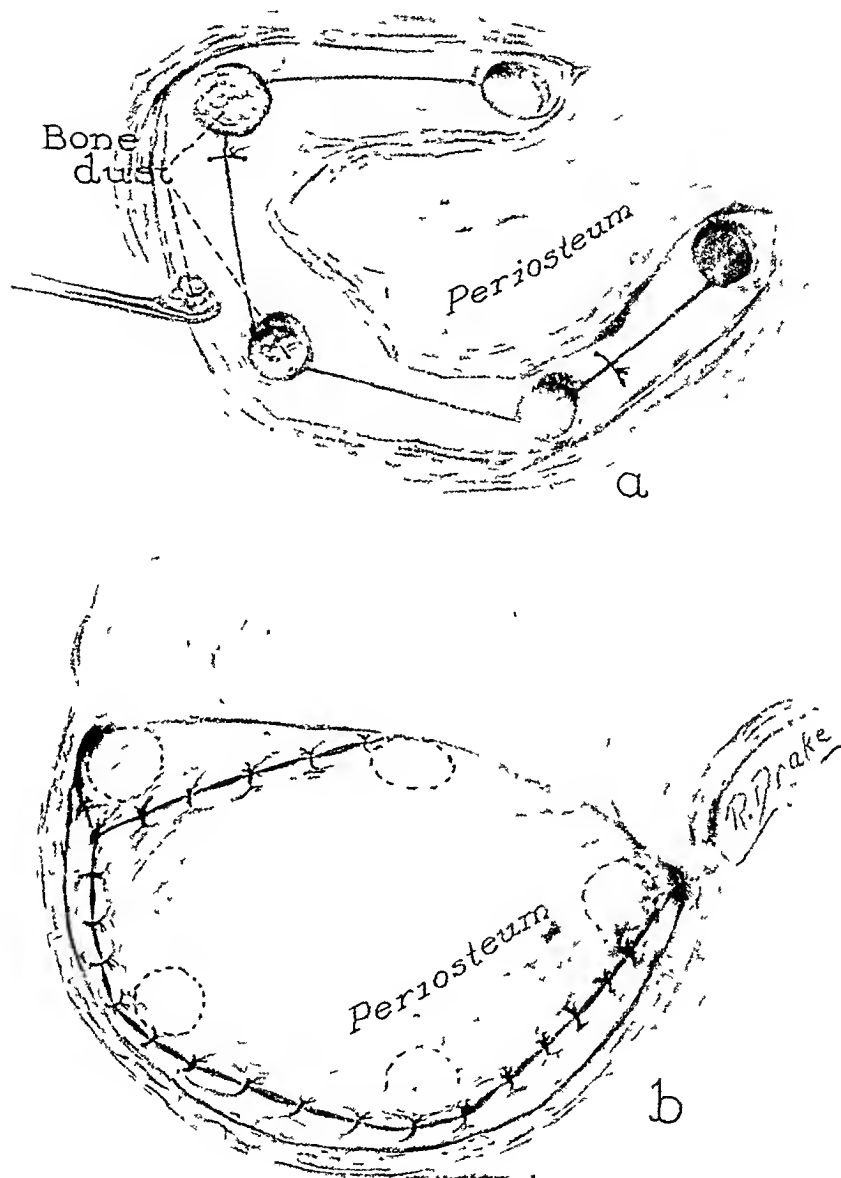
FIG. 109. Closure of bone flap: (a) Filling of trephine openings with bone dust; (b) suturing of periosteum.

easily falls back into place. There is a difference of opinion with regard to the postoperative drainage of the wound in these cases, some clinics insisting that a small Penrose drain inserted through the dural opening and carried out through the posterior angle of the incision allows for the escape of any residual intradural hemorrhage incident to the operation. In other clinics no necessity for this drainage is

seen, and the wound is closed in the usual manner by approximating the periosteum, galea, and skin with interrupted sutures (Fig. 109).

The postoperative care of these patients is quite important, as is to be expected, and there is occasionally marked edema of the brain following the elevation. Moderate dehydration should therefore be used during the first few days of convalescence, and it may be necessary to do repeated spinal punctures should any evidence of meningeal irritation become manifest. The question of postoperative confinement to bed varies with the individual, although it is usually advisable to keep the patient confined to his bed for a period of from ten days to two weeks. Occasionally there is definite imbalance in the fluid levels, and marked polyuria and polydipsia may occur. In these cases this condition is usually controlled by frequent hypodermic injections of solution of posterior pituitary and if there is evidence of a continuation after the patient has been dismissed from the hospital the nasal insufflation of powdered posterior pituitary can be used with a great deal of comfort to the patient. Frequent postoperative recheck examinations of fields of vision should be done to follow the progress of the recovery.

The pathologic diagnosis of the tissue removed is of importance because of the tendency of some of these tumors to recur, even when a fairly radical procedure has been carried out. The presence of mitotic figures and unidentified cells has in some cases been followed by a recurrence, and for that reason the patient should be warned to return for consultation at the earliest recurrence of symptoms. Here again the question of roentgen therapy or surgical treatment has to be considered and the patient's condition and desires in the matter should be taken into consideration. If for any reason the operation carries with it an increased mortality, roentgen therapy

should be used, and if this is not followed by improvement operation should be carried out immediately. Sometimes repeated treatment with roentgen therapy is followed by control of the growth, and surgical treatment is not necessary.

In recent years, in addition to the surgical treatment for pituitary adenoma, roentgen therapy has been advocated to prevent recurrences.

In the prepubertal form of chromophilic adenoma (pituitary gigantism), operations upon the tumor are rarely indicated. Visual disturbances are infrequent and if any arrest of the disease can be accomplished it is likely to be by roentgen treatment. Acromegalic persons frequently have severe headaches or show evidence of failing vision for which something must be done. It is generally recognized that patients having this type of pituitary lesion respond better to roentgen therapy than do patients having chromophobe adenomas. Following roentgen therapy the headaches of acromegalic persons have been relieved, and the progress of the glandular derangement has been arrested. Even when vision is impaired in acromegalic persons it is probably advisable to try roentgen therapy first, but surgical treatment should be resorted to if there is definite progress and roentgen therapy fails to control it.

Also, surgical treatment has been advocated in those cases in which there is no impairment of vision but in which there has been definite progress of the glandular manifestations. In these cases exposure of the hypophyseal region is advocated with the implantation of radon seeds within the substance of the hypophysis. Improvement has been reported following this type of procedure, but also the mortality is extremely high as a result either of hemorrhage into the gland or of severe postoperative reaction.

Roentgen Therapy. Initial roentgen treatment of the chromophobe adenomas

is still of doubtful value although in some surgical clinics it is a routine procedure. Some extremely brilliant results have been recorded, but unless a patient so treated can be kept under very careful observation, irreparable damage to the optic nerves with severe visual loss may occur. Even complete blindness may occur when roentgen treatments have been given over too long a period. Many of the chromophobe tumors, probably 25 per cent, are largely cystic, and another 25 per cent are radioresistant, which would indicate that not more than 50 per cent of these growths are radiosensitive and capable of response to nonoperative treatment. The surgical clinics which use roentgen therapy as a preoperative measure insist upon following their cases very closely and in the event that there is any progress of the disease surgical treatment can be instituted.

Most of the authorities agree that unless roentgen therapy produces marked improvement in the visual fields and visual acuity within six weeks of the beginning of treatment, surgical intervention is indicated. It is not sufficient for irradiation to prevent further loss of vision and hold it stationary for a time. The results of roentgen therapy sometimes aid in the differential diagnosis because if visual deterioration occurs it may indicate a large spreading tumor—a hopeless situation from the surgical point of view with a high mortality rate. One of the reasons for not using roentgen therapy preoperatively is that sudden blindness has occurred following treatment because of the enlargement of the tumor and increased pressure on the optic nerves.

## RESULTS OF TREATMENT

The decrease in mortality rate in operations on pituitary tumors is due in part to early diagnosis and operation in the earlier stages of the disease. The general condition of the patient and the use of roentgen therapy, in older people in advanced stages, have lowered the mortality. The use of blood transfusion both preoperatively and postoperatively, the careful selection of anesthetics, and improved technic have all contributed to make the operation safer.

Probably the best analysis to date of the results in the treatment of pituitary adenomas is that of Henderson, who reported the surgical results in 338 cases of histologically verified pituitary tumors observed at the Peter Bent Brigham Hospital during a period of 20 years. Only three of the 338 patients could not be followed since their dismissal from the hospital. There were 260 chromophobe adenomas (including 32 mixed adenomas), 67 acidophilic adenomas, and 11 adenocarcinomas. The relative incidence of pituitary adenomas is shown in Cushing's series of 2,023 verified intracranial tumors in which there were found to be 17.8 per cent of cases of chromophobe adenomas with local compression, acidophilic adenomas with general constitutional disturbances, as well as local effects in addition, and adenocarcinomas which tended to infiltrate surrounding structures.

The late results in Henderson's report, analyzed on the basis of the duration of improvement after operation, indicated marked variability in the rate of growth and behavior of the chromophobe adenomas. After a successful transphenoid operation without irradiation, some patients had no further trouble for as long as 20 years. On the other hand rapid recurrence within two or three years took place in other cases even after the more radical transfrontal operation plus roentgen treatment. Many patients maintained an improved status for from 10 to 20 years and 95 per cent of those who had a recurrence showed indications of it within five years after operation.

The clinical course of the acidophilic adenomas was found to differ from that of

the chromophobe adenomas. The two types of symptoms (visual and systemic) were found to have spontaneous remissions and exacerbations and responded differently to treatment. Marked improvement in vision might follow operation but no effect on the severe headaches was noticed, especially in cases in which the tumor was small. Systemic disturbances were found to be the most serious because of the deleterious effects of the hormone secretion on the cardiovascular system and on sugar metabolism. The operative mortality rate was found to be slightly higher than for the chromophobe adenomas, but the late surgical results appeared to be better. The acidophilic tumors were more amenable than the chromophobe tumors to roentgen therapy. The adenocarcinomas were found to need more thorough pathologic study. Clinically, some of them were found to behave like chromophobe adenomas; others, however, were hopelessly malignant, infiltrating the base of the skull and producing multiple cranial-nerve palsies.

## SUMMARY

Tumors of the hypophyseal region produce two distinct types of symptoms: (1) Those resulting from pressure upon contiguous structures, and (2) those resulting from glandular disturbances.

The evidence of pressure is found in the roentgenogram of the skull, in which the sella turcica is enlarged or eroded, in headache due to stretching of the dura, and in changes in the optic fundi or perimetric fields consisting of pallor of the optic disks or scotoma and hemianopia. Hypophyseal lesions consist of pituitary adenomas, craniopharyngiomas, suprasellar meningiomas, aneurysmal glioma of the optic chiasm, chiasmal arachnoiditis, cholesteatomas, and chordomas.

The obvious treatment of all lesions except the adenomas is surgical and consists of the transfrontal intracranial exposure, with the exception of aneurysm, for which ligation of the carotid arteries may be necessary. Roentgen therapy is sometimes used in the treatment of pituitary adenomas, but even those who are enthusiastic caution that surgical treatment should be used if improvement does not take place within six weeks. The postoperative use of roentgen therapy is also advised in those cases in which the entire tumor cannot be removed or the microscopic appearance of tissue suggested malignancy.

The operative mortality rate of hypophyseal lesions has been markedly lowered because of early diagnosis and a more careful selection of cases for operation. Restoration of vision and in some cases return of glandular function have been obtained following operation.

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# 12

# Intrinsic Tumors of the Cerebellum and Brain Stem

## Paul C. Bucy, M.D.

## INTRODUCTION

The only possible justifications for a chapter such as this are (1) the outlining of a personal technic from which other neurosurgeons may wish to adapt certain portions to their own use; (2) the discussion of the indications for operation, operability, preoperative preparation, and the handling of complications, all of which are matters constantly worthy of discussion and the subject of individual differences; and (3) the presentation of operative technic for the intelligent comprehension of the problem by the neurologist and general practitioner who never propose to grasp the scalpel. Under no circumstances is this chapter to be construed as encouraging—or even condoning—operation by one untrained or inadequately trained in the intricacies of neurosurgery and supported only by his own ignorance and indifference to his patient's welfare, which on occasion pass for surgical courage. The author implores his readers to protect him from being *particeps criminis* to such a miscarriage of the surgeon's privileges and duties

Obviously if surgical indications, operability, and extent of the surgical intervention are to be discussed, the nature of the pathologic lesions must be considered. All too frequently the fact that the patient harbors a tumor is the sole indication for operation. Whether it can be removed, whether there is any reason to believe that the patient can be materially benefited, cannot be ignored in considering the advisability of intervening surgically. Failure to weigh these matters results in useless operating, serious injury to the patient, and numerous fatalities none of which benefit mankind or medical knowledge but instead bring disrepute upon a worthy branch of the profession and overshadow its meritorious accomplishments.

## PATHOLOGY

In dealing with tumors of the cerebellum and brain stem we are frequently confronted with tumors which may be "malignant" for one or both of two reasons They may be incurable because of their location in the pons or medulla oblongata regardless of their pathologic nature or they may be so because of their tendency toward rapid growth, invasion, and metastasis in the cerebrospinal-fluid spaces. Fortunately, many cerebellar tumors fall in neither of these categories and can be satisfactorily dealt with. The frequent occurrence of these benign cerebellar tumors, particularly in childhood, furnishes neurosurgery with one of its greatest opportunities.

TUMORS OF THE BULB

Tumors arising in or predominantly occupying the medulla oblongata are rare, though they do occur,[24,25] whereas tumors of the pons are common, forming perhaps 15 to 20 per cent of the brain tumors of childhood.[6] It is not uncommon for such pontine tumors to spread caudally into the plastic invasion almost always extends to both sides. Occasionally these tumors break through the surface of the brain stem, usually on the under surface of the pons, and then lead rather rapidly to compression of the bulb, obliteration of the fourth ventricle, and the development of an internal hydrocephalus and the typical
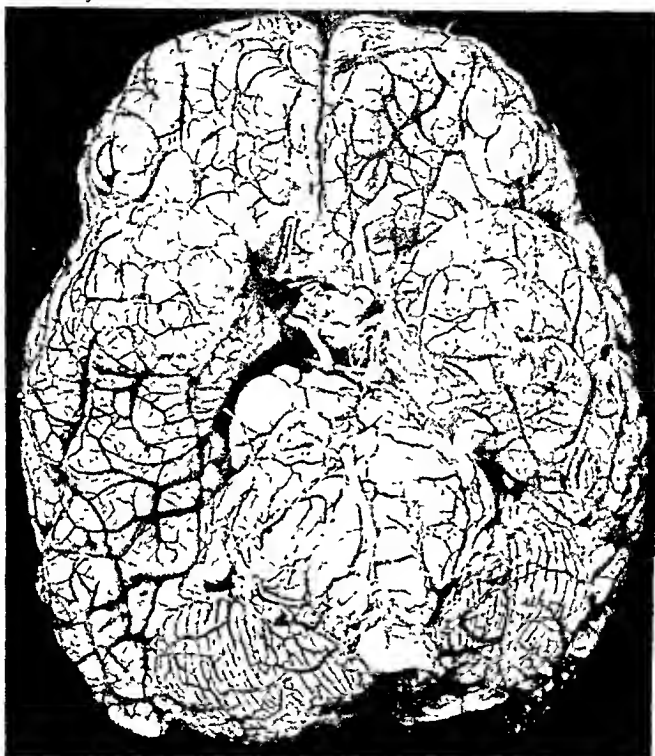


FIG. 110. Glioma of the pons. There is a marked nodular enlargement of the pons which extends forward into the mesencephalon and caudally into the medulla oblongata.

medulla oblongata or cephalad into the midbrain (Fig. 110).

Almost all of these tumors are gliomas which tend to infiltrate among the nuclei and fiber tracts of the brain stem, destroying some, compressing others, and merely pushing some aside. Although the involvement they produce is usually more marked on one side than on the other, the neo-

manifestations of intracranial hypertension (Cases 58 and 59[6]). Barring such a development the ventricular system usually remains patent and intracranial hypertension develops late, if at all.

Even more rarely these tumors may break through the pia mater to be disseminated over the surface of the brain and spinal cord through the cerebrospinal fluid

(Case 61'), or they may, as Dandy[18] has noted, erupt out of the substance of the brain stem to form papillomatous masses in the fourth ventricle or lateral recess.

In view of their gross similarity, the constancy of the clinical picture, and the fatal outcome, the classification of these tumors on the basis of their microscopic

chanan and Bucy[6] did, is a matter of secondary importance.

In addition to the all-too-commonplace gliomas of the pons there occur, far more rarely, *capillary angiomas* of the pons as reported by Michael and Levin.[34] These angiomas may be associated with a cystic cavity within the brain stem or with a lo-



FIG. 111. Telangiectasis of the pons which has produced a circumscribed intrapontine hematoma.

appearance is, at present at least, largely a matter of academic interest. Whether one classifies them all as spongioblastomas of varying degrees of malignancy as Pilcher[37] has done or attempts to divide them into astrocytomas, spongioblastomas, and glioblastomas multiforme comparable to the classification of gliomas elsewhere in the central nervous system as Bailey, Bu-

calized hematoma such as was present in their case[34] (Fig. 111). Such an angioma was probably responsible for the encapsulated hematoma of the pons reported by Dandy.[18]

In addition we have seen small, round, cherrylike angiomas lying on the dorsal surface of the medulla oblongata just at the posterior extremity of the fourth ven-
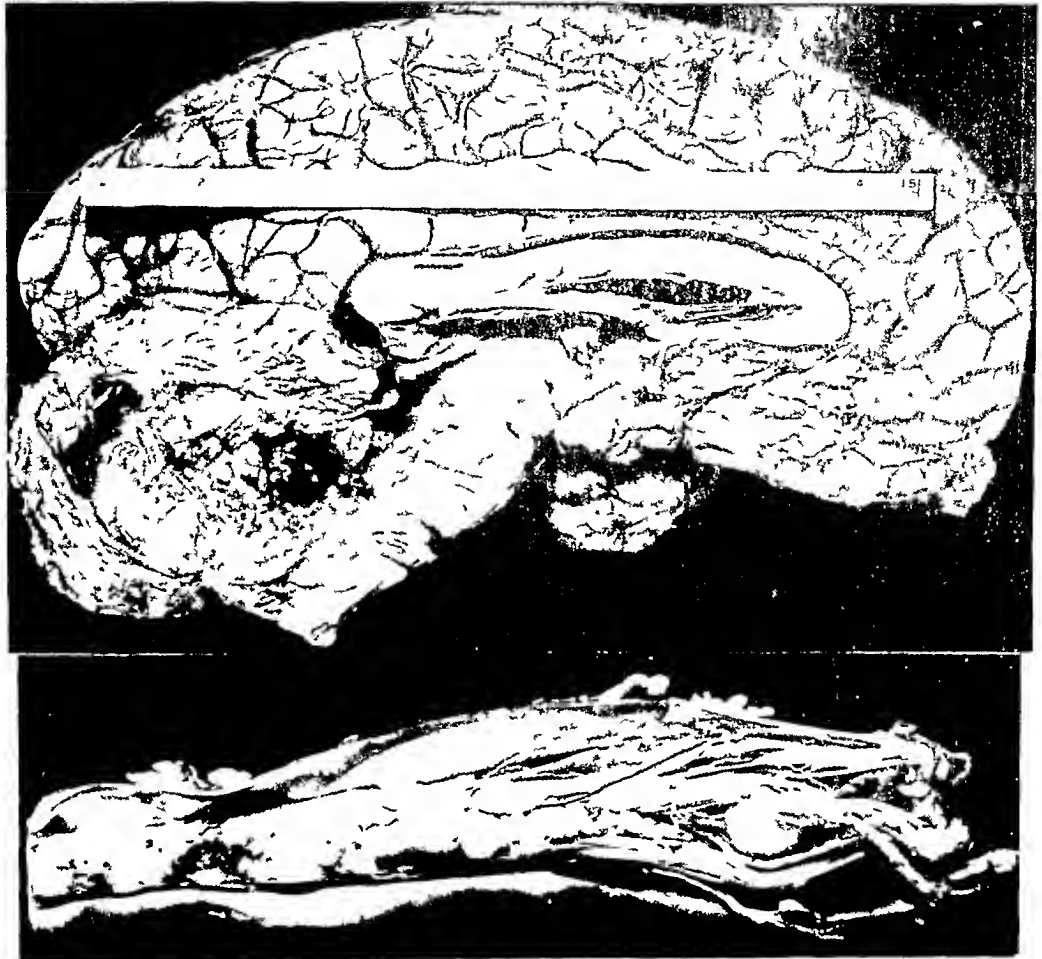
Fig 112 Medulloblastoma cerebelli  In the uppermost figure the tumor can be seen replacing the central portion of the cerebellum overlying the posterior part of the fourth ventricle. Tumor has been implanted in both the third and fourth ventricles by spread through the cerebrospinal fluid

In the lowermost figure tumor which has spread downward in the subarachnoid space has covered the lumbrosacral spinal cord and formed a nodule among the roots of the cauda equina

tricle (Fig 116) A similar tumor has been reported by Dandy[18] on pp 641–642 of the work cited in the bibliography. He has illustrated the successful removal of a tumor of this type and location  Usually these highly vascular masses are quite firmly attached to the underlying medulla oblongata by numerous penetrating blood vessels, which makes any surgical attack upon them extremely hazardous  It is of course not surprising that these blood-vessel tumors should arise here as the area postrema which lies at the posterior end of the fourth ventricle just beneath them is one of the extremely vascular areas of the brain[42] Not all of the vascular tumors
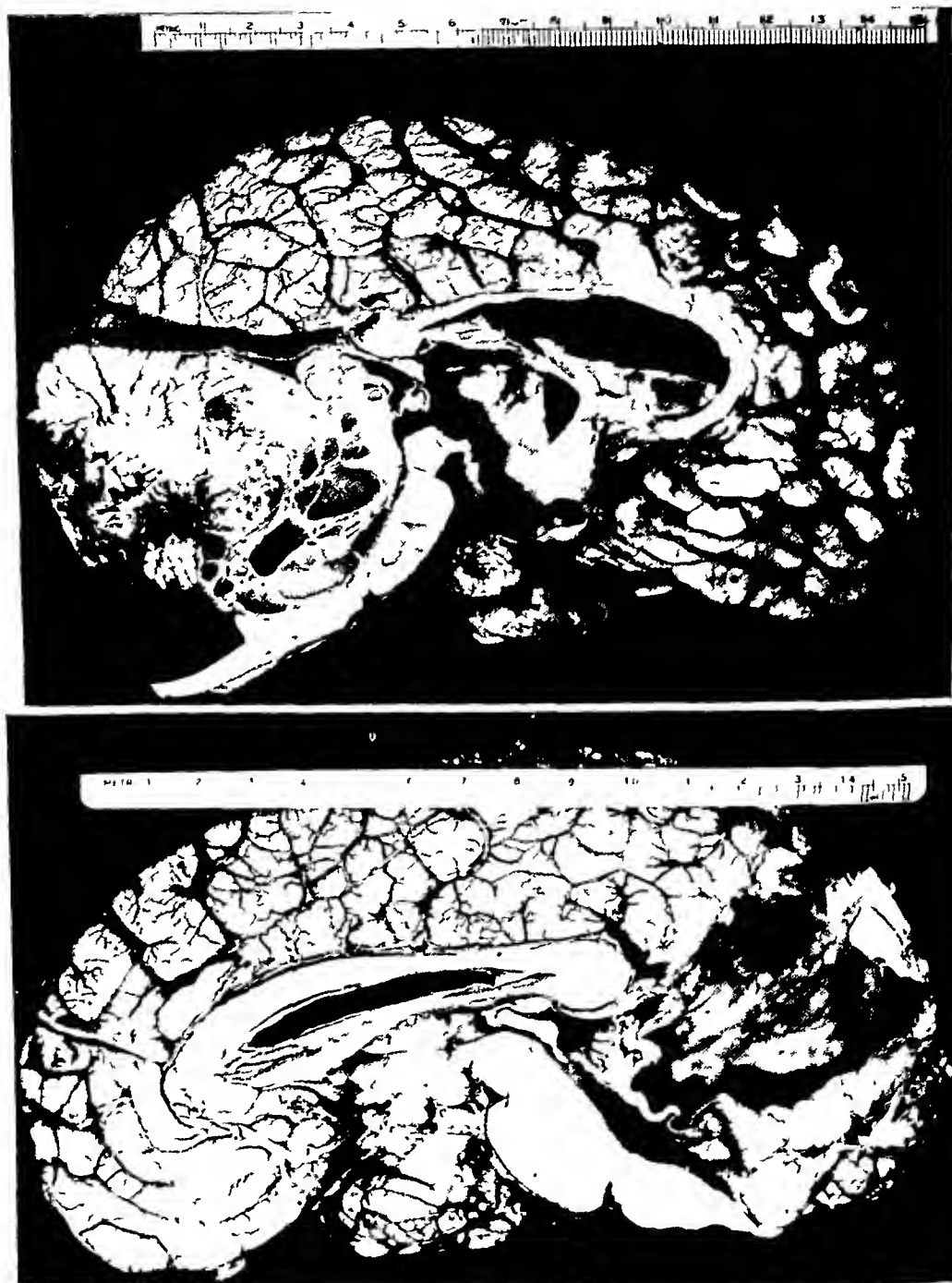
FIG. 113. (*Top*) Astrocytoma of the cerebellum and fourth ventricle. There are numerous cysts within this centrally placed tumor which is adherent to much of the floor of the fourth ventricle (cf. Fig 122) and has markedly compressed the brain stem.

FIG. 114. (*Bottom*) Cystic astrocytoma of the cerebellum. The small mural nodule of tumor is seen in the anterosuperior wall of the cyst. This adolescent girl was killed by an ill-advised lumbar puncture performed in another hospital.

which occur in this region can be classified as angiomas although the hemangioblastomas which occur in this same location (Cushing and Bailey,[16] Levin[31]) are probably closely related.

### TUMORS OF THE CEREBELLUM

Those tumors which arise within the cerebellum form the largest group of tumors within the posterior fossa. There are four such tumors which predominate. Two (the malignant tumors of the cerebellar midline and the astrocytomas) are characteristically tumors of childhood, while the hemangioblastomas and the metastatic carcinomas almost always develop in adults. The other gliomas which involve the cerebellum—spongioblastomas, neuroepitheliomas, medullo-epitheliomas, and astroblastomas—are all relatively rare and need concern us no further here.

Malignant Tumors of the Cerebellar Midline. The malignant tumors of the midline are of two types: (1) The medulloblastomas and (2) the sarcomas of the pia-arachnoid membrane. Although they are readily distinguishable microscopically, they are practically identical in microscopic appearance (Fig. 112). Both are soft, friable, and vascular. They are fleshy in appearance and almost always develop in the postero-inferior part of the vermis. Both tend to spread widely over the central nervous system through the subarachnoid space (Fig. 112). Both tumors are very cellular and contain a variable number of mitotic figures. However, whereas the medulloblastoma is characterized by very little connective tissue and that limited to the walls of the thin-walled small blood vessels, the sarcomas contain a network, more or less extensive, of fibers of reticulin which enmesh the cells of the tumor. The medulloblastomas are almost limited to early childhood and occur most frequently in boys about five years of age.[6] Sarcomas, on the other hand, show less sexual selec-

tivity and are more widespread in their age distribution, and, although more prevalent in childhood, are seen also in early and even middle adult life. Furthermore, with a decompression and radiation therapy the sarcomas, particularly when they occur in adults, offer a somewhat better prognosis and with such treatment are not incompatible with 5 to 11 years of relatively useful and comfortable life. However, the children suffering from medulloblastomas very rarely survive as long as five years after the onset of symptoms regardless of the nature of the treatment.

Astrocytomas. The astrocytomas, which are fortunately the most common single type of cerebellar tumors, have a far more favorable outlook. With appropriate treatment the mortality should be reduced to almost zero and permanent cures are the rule. Grossly these tumors are divisible into three groups: (1) Those that arise from the walls of and lie within the fourth ventricle (Fig. 113); (2) those that involve the vermis predominantly, and (3) those in which one cerebellar hemisphere is predominantly involved. Rarely such a tumor may involve the entire cerebellum (Case 34[6]). These tumors, unlike similar tumors in the cerebrum, are usually sharply circumscribed, and, although they are never encapsulated and always invade the neighboring cerebellum somewhat, the invasion is rarely extensive. They vary from pink to brownish-gray in color, and from firm and fleshy to gelatinous in consistency. They are avascular. They are commonly cystic, particularly those which involve the cerebellar hemisphere (Fig. 114). In such cases the solid tumor usually lies in the region of the vermis, forming only the medial part of the cyst wall (Fig. 121). However, enormous solid tumors of the cerebellar hemisphere are by no means unknown (Bucy and Gustafson[11]) (Fig. 115).

Microscopically these tumors are relatively acellular, are composed of variable

percentages of fibrillary and protoplasmic astrocytes, and contain no mitotic figures.[11] Areas of degeneration, necrosis, and liquefaction are common (Fig. 113).

Hemangioblastomas. These develop from the blood vessels and connective tissue of the leptomeninx of the cerebellum.

rather than destroy cerebellar tissue the manifestations of cerebellar dysfunction are often surprisingly slight. The location of the nodule of tumor is frequently revealed by the convergence of several large blood vessels, principally veins, upon that point (Fig. 123).



FIG. 115. Solid astrocytoma of the cerebellum found in a small boy. There are areas of degeneration in the center of the tumor. The tumor is fairly well circumscribed and the line of junction with overlying cerebellar tissue is moderately sharp.

They may occur anywhere over its surface, but are most common in the hemisphere (Fig. 116). Although large, solid hemangioblastomas have been encountered (Cushing and Bailey[16]) the actual tumor usually consists of a small nodule on or near the surface of the cerebellum, which is associated with a large cyst filled with yellow fluid. These cysts commonly occupy the greater part of the cerebellar hemisphere Except for the nodule of tumor their walls are formed by a layer of gliosis and are not neoplastic. As they usually displace

It is noteworthy that these tumors are commonly associated with abnormalities elsewhere. Their association with angiomas of the retina and cysts of the liver and kidney has often been pointed out, but it has not been commonly recognized that they are frequently associated with other vascular neoplasms elsewhere in the central nervous system. The author has operated upon one patient who had three vascular tumors in the cerebellar fossa, a hemangioblastic cyst of the left hemisphere, a solid hemangioblastoma of the right cerebellar

tonsil, and another solid tumor lying on the dorsum of the posterior part of the medulla oblongata (Levin[31]) (Fig. 116).

In a thorough survey of the literature Levin[31] found that in every one of the ten cases in which a complete autopsy had been performed the spinal cord contained one or more additional hemangioblastic tumors. Other tumors may occur in the brain stem

Metastatic Carcinomas. The cerebellum is one of the more common sites for implantation of a metastatic carcinoma. These tumors frequently arise from bronchiogenic carcinoma of the lung, but may have spread from any location in which primary carcinomas are known to occur. Every adult patient who is suspected of harboring a cerebellar tumor should be re-
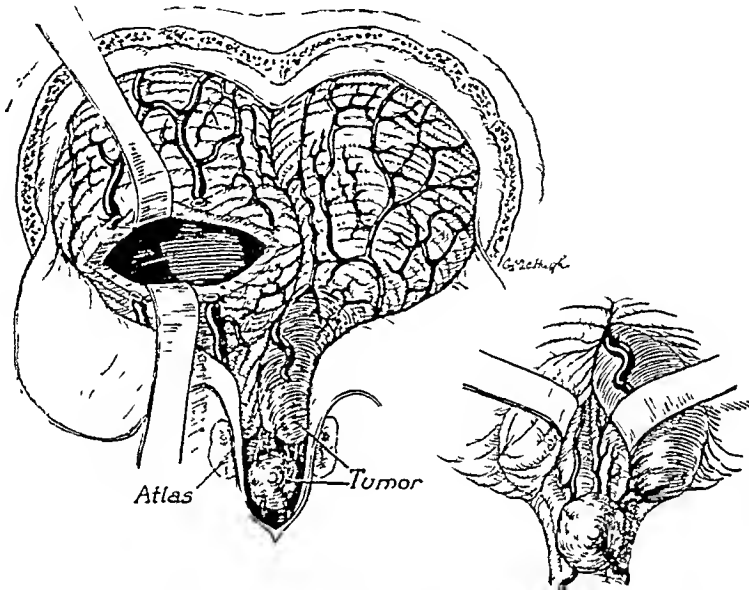


FIG. 116. Multiple hemangioblastomas. One lesion in the left hemisphere was cystic and the mural nodule of tumor could not be located. Another tumor in the right tonsil was solid, as was a third nodule lying on the dorsal surface of the medulla oblongata a short distance caudal to the fourth ventricle. (Previously published by Levin.[31])

(six out of 16 cases). The cerebrum is far less commonly involved. That there is a hereditary factor in many of the cases of cerebellar hemangioblastoma has now been firmly established (Lindau,[32] Levin[31]).

As previously noted, hemangioblastomas of the solid variety may develop on the dorsal surface of the medulla oblongata just posterior to the calamus scriptorum. Cushing and Bailey[16] (Case XVI, pp. 114–118[16]) have reported and illustrated a large tumor of this type.

garded as suffering from metastatic carcinoma until proved otherwise, and a roentgenographic examination of the lungs should form a part of their routine examination. Hemangioblastoma, the only other tumor that involves the adult cerebellum with any degree of frequency, is actually a rare tumor (1.2 per cent of all intracranial tumors in Doctor Cushing's series[15]).

Metastatic carcinomas usually present a typical appearance grossly. They are firm in consistency, though their centers are

often necrotic or cystic. They are pinkish-gray in color. They are usually globoid and fairly well circumscribed. The ease with which they can usually be enucleated is apt to be deceptive to the unwary. Multiple metastases to the brain are common. Unlike carcinomas, metastatic sarcoma of the cerebellum is rare.

Congenital Tumors. Rarely congenital tumors—*teratomas, dermoids,* and *epidermoids*—may involve the cerebellum (Sweet[40]) and *chordomas* growing back-

were entirely those of intracranial hypertension resulting from obstruction to the fourth ventricle. They were completely relieved by evacuation of the cyst and removal of its walls.

TUMORS OF THE FOURTH VENTRICLE

Two tumors are most often found in the fourth ventricle (1) ependymomas and (2) papillomas of the choroid plexus—although rarely others, such as astrocytomas, angiomas, etc., may also be found there. Of
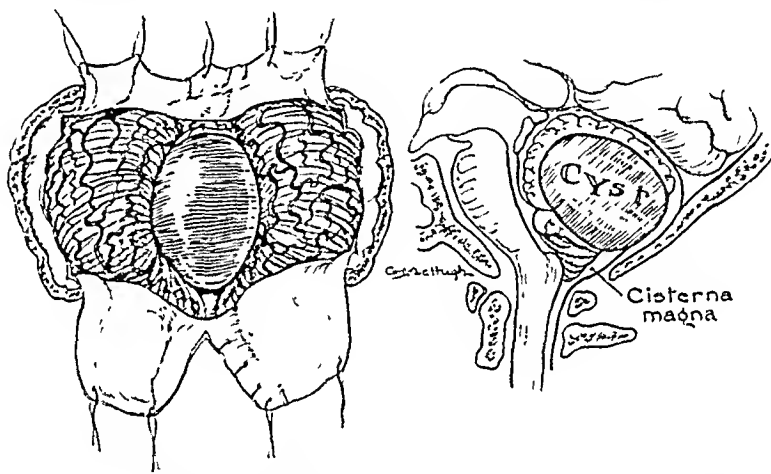


FIG. 117. Benign arachnoid cyst of the cerebellum in a 34-year-old woman. The cyst was separate from the subarachnoid space and cisterna magna and apparently resulted from secretion of fluid by a small tuft of choroid plexus found attached to its wall. Evacuation of the cyst and removal of the wall in 1936 resulted in complete relief of symptoms to date. (Elaborated from sketch made by operator after operation.)

ward from the spheno-occipital synchrondrosis may compress the brain stem (Van Wagenen,[42] Bailey and Bagdasar[7]).

The author has encountered one benign, nonneoplastic, noninflammatory cyst of the leptomeninx compressing and overlying the vermis, which was apparently congenital (Fig. 117). This cyst was formed by the arachnoid membrane but was separate from the subarachnoid space. Attached to a part of the wall was a small tuft of choroid plexus which apparently supplied the fluid within the cyst. The symptoms

the two, ependymomas are the more common (Fig. 118).

Ependymomas. These arise from the ependymal lining of the ventricle and are, therefore, always attached to the wall. Unfortunately, this point of attachment is frequently on the floor of the ventricle. This, in addition to the fact that the brain stem is always severely compressed and therefore damaged, makes extirpation hazardous. As Cushing[15] noted, "The tumors are firm and are evidently enucleable. The temptation consequently is strong to at-

tempt their total removal but owing to their dangerous position this has usually led to a fatality."

Papillomas. Papillomas arise from the choroid plexus in the roof of the fourth ventricle or may lie in the cerebellopontine angle, having arisen from the choroid plexus projecting from the lateral recess of the fourth ventricle. They are firm, cauli-

without undue risk. When, however, his life is endangered, surgical intervention should be entertained only if there is some opportunity of saving it under bearable circumstances. The mere presence of a tumor is not of itself adequate indication for an operation, and this fact is frequently lost sight of.

All factors must be taken into consider-
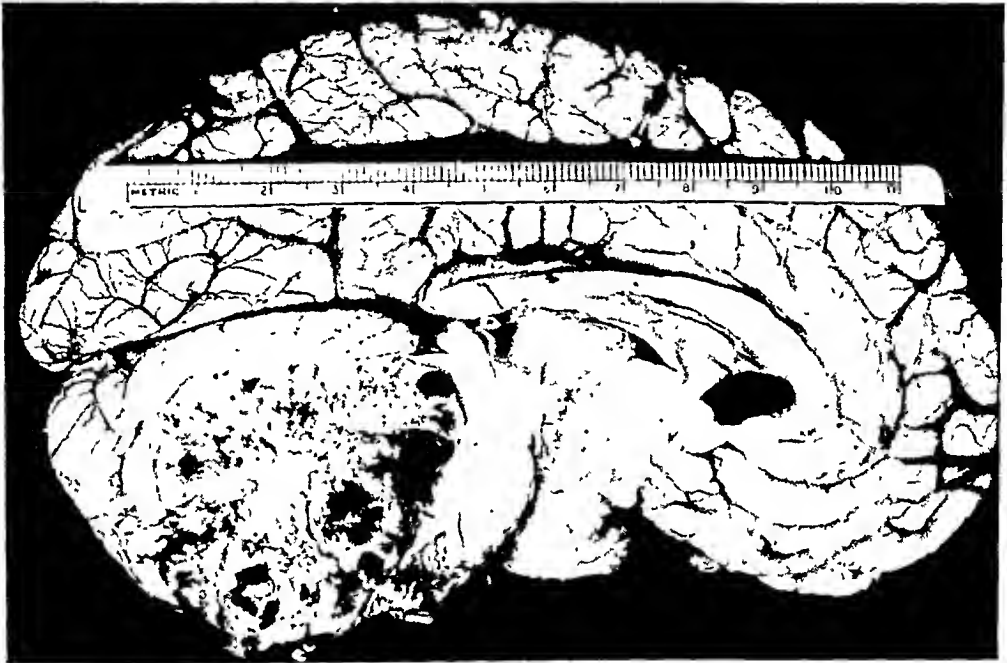


FIG. 118. Ependyoma of the fourth ventricle. The lower end of the brain stem was inadvertently removed at autopsy. The cerebellum is displaced upward and backward and compressed by the tumor.

flower-like growths which are usually excessively vascular. On occasion they have been known to spread by "seeding" through the pathways of the cerebrospinal fluid.

## INDICATIONS FOR OPERATION

Any surgeon should always remember that there are only two possible reasons for an operation. If the patient's life is not imperiled the only indication for operation is a good chance of improving his condition

ation: the patient's present condition, what the future probably holds for him without an operation, the dangers of an operation, and the probable results of the operation. Certainly an operation that has no chance of success or that promises to leave the patient in a hopeless and helpless condition is not justifiable. The performance of such operations can serve only to bring disrepute upon a branch of the profession in which the hazards are already great and

against which, as Foster Kennedy said, "the dice of the gods are loaded."

## GLIOMAS OF THE BRAIN STEM

Diagnosis of a glioma of the brain stem is rarely difficult. Usually the first manifestations are paralyses of one or more cranial nerves. These are commonly associated with vomiting, but other evidences of intracranial hypertension (such as papilledema, separation of the cranial sutures, elevation of the pressure of the spinal fluid) are rarely present until much later in the course of the disease, if at all. Later, signs of involvement of the corticospinal motor pathways and of cerebellar-fiber systems appear. Sensory changes over the extremities and trunk are often absent and rarely severe with gliomas of the brain stem. Other neoplasms in the posterior fossa, when seen very early in their course, may not be associated with definite objective evidence of increased intracranial pressure but such manifestations are rarely absent for long. Cerebellar neoplasms are not infrequently associated with cranial-nerve palsies. But when such occur they usually occur singly and are rarely multiple. One of the commonest is a unilateral or bilateral external rectus paralysis of the eyes. This involvement of the abducens nerves is the result of increased intracranial pressure and occurs only when the evidence of that pressure is abundant. Such paralysis will not, therefore, lead to confusion with that which results from a glioma of the brain stem as in such cases intracranial hypertension is usually mild or absent. Occasionally a mild unilateral facial weakness may appear in association with a cerebellar tumor. Much less frequently other cranial nerves may be involved, but the absence of evidence of extensive involvement of the brain stem plus the presence of increased intracranial tension readily differentiates these tumors which lie outside the brain stem.

It is questionable whether there is ever any excuse for an operation upon a patient suffering from a glioma of the brain stem when the diagnosis is definite. Operations upon these tumors are, in our experience, never beneficial (Bailey, Buchanan and Bucy[6]). Only in those uncommon cases where the diagnosis is uncertain is an exploration justified. It is, of course, many times worse to overlook an astrocytoma of the cerebellum than it is to operate upon a pontine glioma. It should be noted, however, in contrast with our experience and opinion in this matter, Foerster[23] is definitely of the opinion that a decompression, particularly in those cases with increased intracranial tension, is often beneficial although permanent cure is unobtainable. It is noteworthy that his best results were obtained in adults rather than in children.

## MALIGNANT GLIOMAS OF THE CEREBELLUM

Unfortunately, the malignant tumors of the cerebellar midline (medulloblastoma and sarcoma) cannot be diagnosed with the same certainty as the pontine gliomas. Were this possible, practically all neurosurgeons would be inclined to agree with Cutler, Sosman and Vaughn[17] and treat all such cases with the x-rays rather than operate upon them. However, every neurosurgeon has had the experience of making a preoperative diagnosis of a medulloblastomas cerebelli only to find that he is dealing with an enucleable astrocytoma or an ependymoma. It is hardly justifiable to submit such cases to the dangers to life and vision which are inherent in radiation therapy, due to the resultant edema and the delay essential to determine the results of such treatment, unless one is practically certain of the diagnosis and can provide some means of obviating the dangers. It was with this possibility in mind that Bailey, Buchanan and Bucy[6] suggested on p. 89 of the work cited in the bibliography that in suitable cases continuous ventricu-

lar drainage be established by the insertion of a T-shaped needle before instituting x-ray therapy. As yet no opportunities to test this proposal have been utilized. Whether the results will justify the procedure or the dangers damn it cannot be said. However, as Grant[29] has shown, the dangers of radiation therapy in the absence of a decompression are very real. In one of his cases so treated "medullary collapse and subsequent death followed deep roentgenization without operation." It should be borne in mind that no procedure or group of procedures (decompression, extensive extirpation, intensive x-ray therapy) has been able to prolong the life of a single patient suffering from one of these malignant tumors of the cerebellum for more than a few years (usually two or three, rarely more than five), whereas the majority of astrocytomas of the cerebellum can be cured. It is therefore our duty to do nothing which might impair the chances of a single patient suffering from a benign removable cerebellar glioma.

The indications for the present at least are to explore all such cases as it is not possible accurately to differentiate removable from malignant invasive tumors except by exposure and biopsy.

### Benign Tumors of the Cerebellum

The development of progressive symptoms of unilateral cerebellar involvement in a child is highly suggestive of an astrocytoma, in an adult of a hemangioblastoma. However, it should always be borne in mind that astrocytomas may be associated with manifestations of midline cerebellar involvement only and that hemangioblastomas may be present in the complete absence of signs or symptoms of cerebellar dysfunction.

In all cases in which the diagnosis of a benign tumor of the cerebellum is made an operation with complete removal, if possible, is indicated as soon as is compatible with the patient's general condition.

## PREOPERATIVE PREPARATION

In the ordinary patient who is to be operated upon as soon as the diagnosis is made, attention should be directed toward three things: (1) Getting the patient in the best possible physical condition for the operation, (2) such general measures as are necessitated because of the operation, and (3) preparation of the operative field.

Many of these patients will have been vomiting and taking little by mouth prior to the operation. Their fluid stores should be replenished by the hypodermic injection of adequate amounts of normal saline, if necessary, or by a blood transfusion if such is warranted by any considerable anemia. In all instances blood should be available throughout the operation for transfusion and should be used without hesitation. The transfusion of blood is frequently a life-saving measure during one of these operations and may easily mean the difference between success or failure.

Only occasionally are these patients sufficiently apprehensive prior to the operation as to cause sleeplessness. When this occurs, however, one of the rapidly acting barbiturates such as pentobarbital sodium in doses proportionate to the patient's age and size should be used. No other medication should be given preoperatively and above all *morphine should be avoided*. It is a severe depressant of the respiratory center and has been responsible for preoperative deaths among victims of intracranial tumor. Atropine is often desirable to prevent the excessive outpouring of bronchial secretions, which may otherwise be so annoying.

Whenever the intracranial tension is high the usual preoperative enema should be omitted as it may provoke a fatal herniation of the cerebellar tonsils. The enema should be given if at all on the evening

preceding the operation, thus avoiding awakening the patient unnecessarily early in the morning or delaying the operation. Furthermore, an enema just prior to the operation induces undesirable apprehension and tension in the patient and may in some cause nausea. Many nurses have been trained to give repeated enemata until the "returns" are clear. This is often a very exhausting procedure which may be desirable with some types of surgery but is not only unnecessary but actually harmful to neurosurgical patients.

The operative field should not be prepared until just before the operation. Whether this preparation is done in the operating suite or in the patient's room is immaterial. The hair should all be cut from the head and the entire head carefully shaved. Any unusual amount of oily débris can then be removed with soap and water, alcohol and ether, if necessary.

The severely dehydrated and/or stuporous patient presents additional problems. Immediate operation upon such patients should be avoided, if possible. The procedure recommended by Fincher[22] has proved life-saving in many of these cases. A trephine opening is made in the frontal or occipital region and a T-shaped needle is inserted into the lateral ventricle to provide continuous drainage and reduction of increased intracranial pressure. Except in those few cases in which the direct compression of the brain stem is unusually severe, this procedure promptly restores the patient to consciousness and his general condition rapidly improves as he is able to take and retain food and fluids. At first thought it would appear that this method would present considerable danger of intracranial infection. However, such has not proved to be the case in the large number of cases in which it has been used, often for as long as three weeks. It has been my practice to cover the wound with two strips of cottonoid soaked in 80 per cent alcohol,

one beneath the flange of the T on either side of the needle. It is, of course, important that the patency of the needle be maintained. To this end it is well to keep the patient flat in bed in order to maintain a constant flow of cerebrospinal fluid. This also serves to keep the needle washed clean and prevent the ingress of infection.

In many of these severely debilitated patients the free use of parenterally administered glucose-in-saline solutions and blood will prove advantageous in preparing them for operation. It is also well to remember that persistent vomiting, particularly in children, results in the depletion of the chloride in their bodies and in acidosis. These are readily corrected by the administration of water, glucose, and sodium chloride. Furthermore, their failure to obtain adequate amounts of food and fluid if sufficiently prolonged will be associated with an avitaminosis which will make the administration of vitamin C, in the form of cevitamic acid or citrus-fruit juices, and of vitamin B, in the form of thiamin chloride or brewers' yeast, of value.

## ANESTHESIA

The choice of the appropriate anesthetic agent is a matter of the greatest importance in all cranial surgery, but is particularly so when the cerebellar fossa is being opened. It is equally important that one have an able, experienced, tireless, and amiable anesthetist. Thus equipped the surgeon can devote his entire attention to the endocranial problems.

Until approximately 15 years ago many of the leaders in the specialty preferred local to general anesthesia for operating upon cerebellar tumors (Frazier,[20] Cushing[11]), although even at that time there was no unanimity of opinion and some surgeons preferred ether for these cases (Naffziger[36]). After not a little experience with local anesthesia, even with small children, the author agrees that "it is remark-

able how well patients, even young children, will endure these long procedures with scarcely any complaint worth recording" (Cushing[14]). But the author is convinced that such an operation to any but a stuporous or comatose patient is a horrible ordeal little short of prolonged torture. The patients' marked aversion to a second operation under similar circumstances reenforces this conviction. Local anesthesia should ·be reserved for operations upon stuporous or comatose patients or for circumstances in which competent anesthetists are not available.

The author's preference is for ether supplied by a vaporizing machine and administered through catheters inserted through the nostrils into the nasopharynx. Several years ago the author discontinued this method for the intratracheal administration of ether, but the high incidence of postoperative pulmonary complications, such as atelectasis, bronchopneumonia, severe tracheal edema, mediastinitis, etc., caused him to abandon the intratracheal administration of ether. The use of intranasal catheters is simple and adaptable to patients of all ages.

A few years ago many neurosurgeons became enamored of avertin (tribromethanol in amylene hydrate) as a basal anesthetic for cranial operations. More recently its use has been considerably reduced. Together with his associates the author used it for several years in many cases, but in recent years its use has been considerably curtailed. It has many disadvantages, particularly for patients with cerebellar tumors. The dose is determined not as with ether and other continuously administered agents by their effect upon the patient but by the patient's weight. The result is a marked variation in its effectiveness. Whereas some patients remain unconscious alarmingly long after the termination of the operation, others begin to awaken and become restless in the midst of the surgical

procedures. It is then necessary to interrupt the operation and administer ether until the patient is asleep again. It is a respiratory depressant and with tumors in the posterior fossa when the central respiratory mechanism is often already interfered with this is particularly undesirable. The author has seen patients with tumors in this location cease breathing after the administration of avertin, before the operation has even begun, and require artificial respiration and emergency ventricular puncture as life-saving procedures.

Almost invariably avertin causes a marked initial fall in the blood pressure, which usually returns to the previous level in from 15 to 30 minutes but occasionally does not do so. Unnecessary delays and injection of stimulating drugs such as ephedrine and adrenalin then become necessary. Furthermore, even that initial fall in the pressure is not insignificant in a patient whose intracranial circulation is already embarrassed by intracranial hypertension. Even brief falls in blood pressure may result in serious cerebral pathology from which the patient may never recover (Miserocchi[35]).

Lastly, avertin is most capricious in children, who require relatively much larger doses than do adults, and the effect in them is even more unpredictable. As the majority of cerebellar tumors are in children, this drug is particularly unsuitable to the surgeon's purpose here.

## OPERATIVE TECHNIC

**Position of Patient.** The position of the patient upon the table is extremely important in these cases. The operative approach is to be largely through the under surface of the skull and the head must be so placed that this is readily exposed. Within recent years several neurosurgeons—particularly De Martel[33] in France and Gardner[27] in the United States—have advocated the sitting position for many cranial opera-

tions, including those upon the cerebellum. However, the depressant effect of this position upon the blood pressure make it particularly undesirable in operations in the posterior fossa Sudden falls in blood pressure are common during operations upon the cerebellum. Such a fall with the resultant cerebral ischemia may well prove fatal unless it can be instantly corrected.

The best position at present is with the patient prone, the shoulders resting upon suitably padded supports and elevated above the level of the table just sufficiently to allow room for expansion of the chest in inspiration The head should be flexed on the neck so as to expose the suboccipital region as completely as possible. The cerebellar head rest designed by Bailey[2] is admirably adapted to placing the head in the optimum position and to readily altering that position during the course of the operation as necessary Unfortunately, many patients with cerebellar tumors have some stiffness of the neck, making flexion of the head difficult Forceful flexion under such circumstances frequently produces apnea due to mechanical shifting of the contents of the cerebellar fossa as a result of pull upon the cervical spinal cord and the cervical dura mater. The position of the head illustrated in various texts and articles is ideal but rarely obtainable, since the models used for such photographs are not suffering from cerebellar tumors. Flexion of the head may also cause compression of the trachea.

It is advantageous that the table be tilted with the head-end up to an angle of 25 or 30° This confers some of the advantages of the sitting position but with a suitable table allows the head to be lowered instantly should that prove necessary.

Preparation of the Operative Field. Once the patient has been placed to the best advantage the skin of the operative field and well beyond it should be prepared Simple scrubbing of the scalp for several minutes with 80 per cent alcohol, as used by Cushing, is a very satisfactory method Some surgeons prefer to use one of the many dye-containing antiseptic solutions commonly in use in other fields of surgery

Once the scalp has been prepared the incision or incisions that are to be used should be marked on the scalp by making a scratch or very superficial incision with the scalpel At intervals of approximately 8 cm. along the incision cross marks should be made to facilitate perfect approximation of the edges of the wound in closure.

The entire field should then be covered by a double layer of thin gauze soaked in a weak solution of mercury bichloride * Towels soaked in a similar solution should then be applied around the field. These may be held in place by towel clips or by sutures passing through the scalp. Sheets should then be placed. Those specially made for cranial surgery and in use throughout this country will be found most satisfactory.

Provision should always be made for a short incision and trephine opening over one occipital lobe through which the lateral ventricle can be punctured. This should be done first, before proceeding with the main part of the operation, for two reasons: *First*, to lessen the increased intracranial tension and thus improve the patient's condition, to lessen the extracranial bleeding which is at times most annoying in these cases, and to decrease the tension in the cerebellar fossa; and *second*, to confirm the diagnosis. Almost every cerebellar tumor is associated with an internal hydrocephalus. If a dilated lateral ventricle is not found the surgeon should seriously consider whether it is wise to continue with the operation before resorting to ventriculography (Fig. 119). A T-shaped needle should be inserted into

* The toxic combination of iodine and mercury bichloride should of course be assiduously avoided

the ventricle and left in place throughout the operation.

Operation. For the majority of cases a curved incision extending from the tip of one mastoid process to that of the other will be found most useful (Fig 120) The center of the curve should lie just above

The author prefers the latter as their use avoids the many instrument handles which otherwise clutter up the field.

The neck muscles are then incised a short distance below and parallel to the superior nuchal line so as to leave a narrow band of muscle attached to the skull to



Fig. 119. Ventriculogram in a case of medulloblastoma cerebelli The lateral ventricles are dilated as is the upper portion of the fourth ventricle into which projects the rounded anterior end of the tumor which fills the posterior part of this ventricle. (Cf Fig 112 )

the external occipital protuberance which can usually be readily palpated and the curve itself should follow the approximate position of the superior nuchal line which is the superior point of attachment of the nuchal muscles

Bleeding from the scalp is readily controlled by the application of a series of hemostats to the galea aponeurotica or of Michel skin clips which include the galea, the scalp, and the gauze on the surface.

which the remainder can be sutured when the wound is closed The muscles attached to the occipital bone below the superior curved line are stripped from the bone with a periosteal elevator and the wound held open by goiter retractors placed on either side. Some surgeons have advocated stripping all the muscles from the skull, leaving no band to suture to, and then in closure to either not suture the muscles or suture them to a series of drill holes in the skull [12]
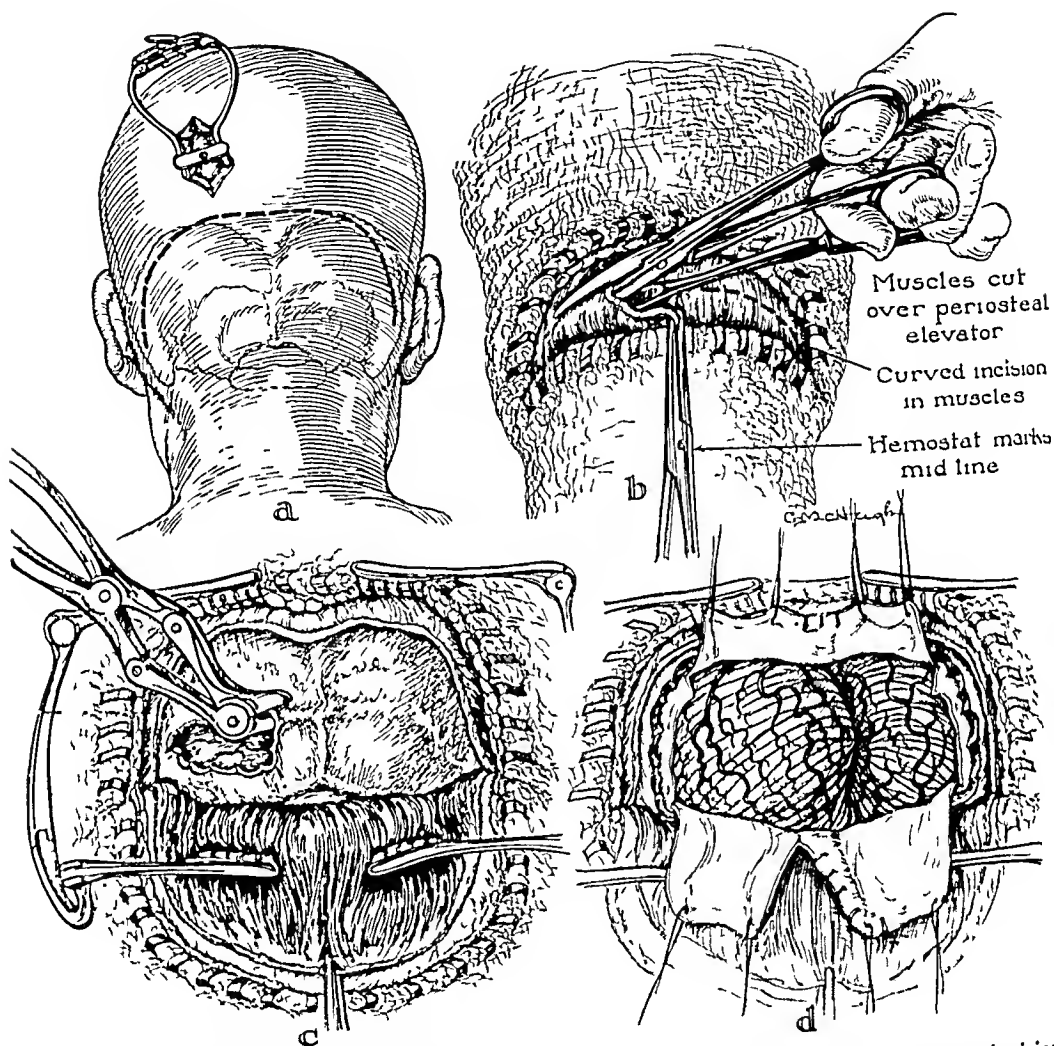
FIG. 120. Exposure of the cerebellum with the more common curved suboccipital incision.

(a) An incision and trephine opening have been made over the left occipital lobe. The scalp is retracted by a "mastoid" retractor. A T-shaped needle has been inserted into the left lateral ventricle. The proposed incision is indicated by a broken line. The surface markings of the bone in the suboccipital region have been drawn in lightly.

(b) The scalp has been incised. Michel skin clips have been applied to the galea, the scalp, and the overlying gauze. A periosteal elevator has been inserted beneath the muscles a short distance below the superior nuchal line. The muscles are being cut transversely with the scissors and will be similarly dealt with on the other side.

(c) The muscles, having been cut, are now reflected and held in place with "goiter" retractors. A trephine opening in the occipital bone is being enlarged with the rongeur.

(d) The bone overlying the cerebellum including the posterior arch of the foramen magnum has been removed. The dura mater has been incised and reflected. Bleeding from the occipital sinus has been controlled with silver clips. The left cerebellar hemisphere is obviously enlarged and the folia widened, indicating the presence of an expanding lesion in that hemisphere. (Continued in Fig. 121.)

This provides a slightly larger exposure of the cerebellum. However, the closure is either more tedious and prolonged or not firm. With the postoperative development of any intracranial hypertension an unsightly hernia or cystic swelling is apt to appear in the suboccipital region. The author therefore reserves this procedure for those unusual cases where it is desirable to explore the superior surface of the cerebellum.

should then be removed with a rongeur, taking care not to strip the transverse or lateral sinus from the bone superiorly. Only at a few points is bleeding to be anticipated during this procedure. In the midline there are usually several large diploic venous channels overlying and paralleling the occipital sinus. Laterally, just posterior to the mastoid processes, are the mastoid emissary veins which are often much enlarged in these cases. Bleeding from both
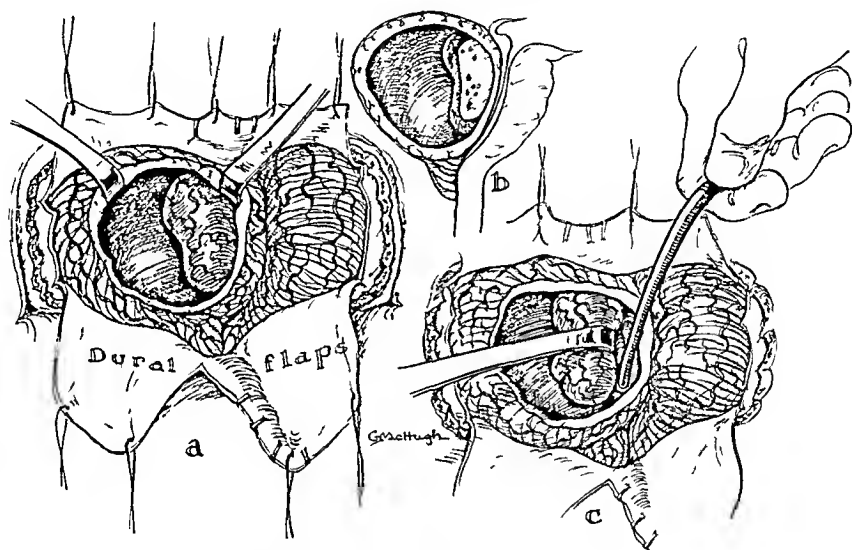


Fig. 121. Cerebellar astrocytoma.

(a) The cystic cavity in the left hemisphere has been exposed by removing a block of the overlying cerebellar tissue. The mural tumor is seen lying in the medial part of the cystic cavity.

(b) Midsagittal section showing the position of the solid tumor just above the roof of the fourth ventricle.

(c) Removal of the tumor by separating it from the surrounding cerebellar tissue with the "sucker."

Once the neck muscles have been retracted a group of emissary veins near the upper midline will usually have been exposed and be bleeding. These can be controlled with bone wax. A trephine opening should then be made over one cerebellar hemisphere and through this the neighboring dura mater can be separated from the bone with a small curved periosteal elevator. The bone overlying the cerebellum

of these sources is readily controlled with bone wax. Inferiorly, on either side of the foramen magnum, is a large emissary vein, the condyloid. It should be avoided, but if opened or torn can be controlled with the coagulating current or a small bit of muscle.

The posterior part of the rim of the foramen magnum should always be removed. The dura mater is adherent at this point

and contains a venous channel. Tearing this can be avoided by exercising a little care in freeing the dura mater from the margin of the foramen. At times it will also prove necessary to remove the posterior arch of the atlas or first cervical vertebra. This can easily be done by retracting the tissues until the arch can be palpated just caudal to the foramen magnum. A longitudinal incision is then made over the center of the arch—the first cervical vertebra has no spinous process. The tissues are then separated from the bone and the bone removed with a small rongeur. Care must be exercised at this point as a circular venous channel lies in the tissues near the bone and the large vertebral arteries are nearby. Troublesome bleeding may develop from tearing the veins and serious complications may arise from interfering with the arteries.

Once the bone has been completely removed the dura mater should be incised. The author prefers a semicircular incision parallel to and a short distance from the superior and lateral margins of the bony defect, plus a longitudinal midline incision in most cases. The free margin of dura mater left superiorly and laterally can then be sutured over the edges of the bony defect, effectively controlling any venous oozing from the region of the lateral sinus. In making the incision in the dura mater it should be picked up on a fine sharp hook and a small nick cut with a scalpel. A grooved director should then be inserted and the opening enlarged. A small spoon can then be inserted beneath the dura mater protecting the cerebellum and its blood vessels from injury. The incision should then be directed toward the midline where the only blood vessels of any consequence in the dura mater of the cerebellar fossa are to be found. The occipital sinus passes downward at this point from the torcular Herophili. The spoon should be carefully and gradually passed beneath

this sinus and the sinus should be cut between a series of silver clips. Occasionally an unusually deep falx cerebelli will be found passing inward from the region of the occipital sinus between the cerebellar hemispheres. This is best attacked by approaching it from both sides.

If on incising the dura mater the cerebellum is unusually tense and tends to herniate through the dural opening a blunt brain-puncture needle should be inserted into both cerebellar hemispheres to find and evacuate a cyst, should one be present. Occasionally it will be possible to obtain some relief by opening the cisterna magna and evacuating fluid confined in it and the fourth ventricle. However, puncturing the lateral ventricles at the start of the operation will greatly reduce the frequency of this dangerous and annoying condition of intracranial hypertension.

As Bailey[3] has well said, "There are many methods of opening the skull—for better or for worse. The really important matter is to know what to do once inside." What to do is dependent upon two factors, apart from the condition of the patient which in itself may exact severe limitations. The important determining factors locally are (1) what type of tumor is present, (2) where it is located, and (3) what does it involve. A detailed analysis of the pathology of intracranial tumors is obviously not for this book, but must be sought elsewhere (Bailey,[3] Bailey and Cushing,[7] Bailey, Buchanan and Bucy[6]). In this discussion the author has had to be content with a few general observations regarding only the more prevalent forms of tumors, and these have been discussed.

*Pontine gliomas* produce a backward displacement of the vermis and tonsils of the cerebellum. When the tonsils are separated, the posterior medullary velum torn, and the fourth ventricle explored, its cavity will be found diminished due to dislocation of the floor dorsalward. Often the familiar

markings of the floor, the median raphe, the striae acousticae are distorted and displaced. When such a tumor is disclosed, immediate closure of the wound, leaving the dura mater open to provide a decompression, is the sole indication.

The *malignant tumors* of the posterior midline of the cerebellum, medulloblastomas and sarcomas, usually demonstrate their presence by a widening of the vermis (Fig. 124) which under other circumstances is usually more or less obscured by the overlying hemispheres. One may also see small opaque grayish-white disks of tumor disseminated over the surface of the cerebellum, evidence that metastases have already been disseminated through the cerebrospinal-fluid pathways. A short superficial incision through the cortex of the vemis will expose the underlying dark red, granular, vascular, friable tumor. A small piece should be taken for immediate microscopic examination, and if this confirms the diagnosis, and it can be confirmed in no other way, the indication is to do as little as possible beyond providing a decompression. Very occasionally this will necessitate removing some of the tumor by suction or blunt dissection in order to relieve the obstruction of the fourth ventricle. It should be borne in mind, however, that each increase in the amount of manipulation of these vascular tumors increases the operative mortality. The author cannot agree with Sachs[38,39] and Cushing[13] that one should make an attempt to completely remove these malignant tumors. Certainly one would not adopt this "conservative" attitude after one or two failures, but now with many years of experience behind us, with hundreds of cases operated upon, the failure of attempts at radical extirpation has been proved beyond doubt. Not one of the 64 patients suffering from a medulloblastoma upon whom Doctor Cushing operated is now alive (Eisenhardt[19]).* Until some new method of attack is brought

forward we cannot hope to help these patients other than temporarily. Elsberg and Gotten[21] have shown that these temporary benefits are as great with biopsy and simple decompression as with more radical extirpation and the immediate mortality rate is considerably lower.

Having determined that such a malignant tumor is present the dura mater should be left open, for practically no decompression is provided if the dura mater is closed. It may be desirable to leave a T-shaped needle in the ventricular wound in order to provide drainage while administering x-ray therapy (Bailey, Buchanan and Bucy[6]). Or such a needle can be inserted just before such treatment is begun if there is to be much delay in its institution.

*Ependymomas* of the fourth ventricle will usually be exposed at operation under the mistaken diagnosis of medulloblastoma cerebelli. They may demonstrate their presence by a tongue of tumor extending down from the fourth ventricle over the posterior part of the medulla oblongata, even into the upper spinal canal. They are generally firmer, grayer, and less vascular than either the sarcoma or the medulloblastoma. It should be recalled that these tumors are often adherent to the floor of the fourth ventricle and compress the brain stem severely, thus accounting for the frequency of respiratory failure during and following operation in these cases, as Bailey, Buchanan and Bucy[6] noted. Attempts at removal are therefore associated with much danger. The author agrees with Cushing[15] who said, "The tumours are firm and are evidently enucleable. The temptation consequently is strong to attempt their total removal, but owing to their dangerous

* One patient whose tumor was originally classified as a medulloblastoma still survived in 1940 after operation in November, 1928, and subsequent x-ray therapy. Recent re-examination of the tumor by Doctor Eisenhardt has shown the original diagnosis to have been in error. The tumor was a leptomeningeal sarcoma.

position this has usually led to a fatality. Cases that have been simply decompressed have survived for many years." In the event that simple decompression does not provide the desired relief a second operation can be made and removal of the tumor, with its attendant dangers and high mortality, undertaken

*Astrocytomas* of the cerebellum usually cystic wall (Fig. 114). These latter cysts apparently arise by transudation rather than degeneration.[11] In those cases in which the cyst involves one cerebellar hemisphere predominantly, the solid portion of the tumor is frequently found in the region of the vermis (Fig. 121) although it may lie on the roof or floor of the cystic cavity (Fig. 114). In such cases the involved
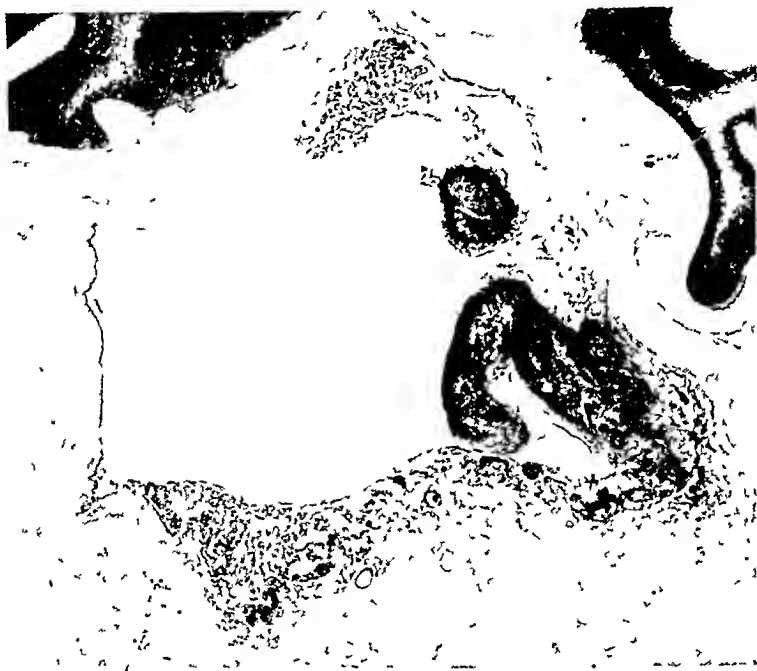


FIG. 122. Astrocytoma of fourth ventricle. Photomicrograph of the fourth ventricle from which an astrocytoma was removed showing the point of attachment of the tumor to the floor of the ventricle.

involve one hemisphere predominantly although they may occupy the vermis, resembling a medulloblastoma grossly, or lie in the fourth ventricle like an ependymoma Though they are usually cystic, large solid tumors do occur (Fig. 115) The cysts are of two types [11] They may be small degenerative cysts lying wholly within the tumor (Fig 113), although more commonly the cysts lie outside the solid tumor which is found in one portion of the hemisphere is larger and feels more tense than the other (Fig. 120) Its medial margin is displaced across the midline compressing the vermis and opposite hemisphere.

After inserting a needle, finding and evacuating the cyst, an incision into the hemisphere is made either with the high-frequency electrical cutting current or with scalpel or scissors, controlling the vessels with silver clips. A single transverse inci-

sion across the involved hemisphere may prove adequate, although removal of a block of the cerebellar cortex overlying the cyst or tumor usually gives a much better exposure (Fig. 121). It is important that the solid portion of the tumor be removed completely, else a recurrence is likely (Cushing[14]). Occasionally the tumor may, however, invade the pons (Bucy and Gustafson,[11] Case 2) or be attached to the floor of the fourth ventricle (Fig. 122) or to the calamus scriptorius (Cushing,[14] Case 22, and Fig. 33). In such cases the surgeon had best be content with an incomplete extirpation, as removal of this last bit attached to the vital centers may prove fatal. In this connection it should be recalled that in many instances where the tumor has been incompletely removed, years have elapsed before a return of symptoms has necessitated reoperation.

For example, in Doctor Cushing's Case 5 he aspirated the cyst on October 23, 1911, it was again aspirated 11 years later in December, 1922, and two years later, on October 23, 1924, the cyst was evacuated and the solid tumor removed. Subsequently the patient remained well. In Doctor Cushing's Case 7 a period of seven years, during which the patient was completely relieved, elapsed between two of the operations, and in his Case 17 seven and one-half years elapsed. Of his cases in which an incomplete extirpation had been made, but in which a second operation had not been necessary at the time of his report, Case 31 had survived for eight and one-half years and Case 38 for seven years. The author has one case (Bailey, Buchanan and Bucy,[6] Case 30) in which the cyst was evacuated but the solid tumor was not removed and the boy has remained in excellent health since the operation on June 28, 1930, over 15 years ago. However, it is noteworthy that in Doctor Cushing's cases requiring re-operation because of recurrence of symptoms the average interval is just over three

years, although there were also intervals of 13, 7, and 6 years.

The method of removal of the solid tumor is a matter of no little importance. Cushing,[14] Elsberg,[20] and others were impressed with the value of the electrosurgical high-frequency current for this purpose. Our experience has led us to use this instrument conservatively, particularly with tumors in and about the fourth ventricle (Bailey, Buchanan and Bucy;[6] see Case 42 and pp. 549–550). The ease with which tumors may be cut from the floor of the fourth ventricle and other vital tissues with the high-frequency current is deceptive. This method is not to be advocated because of the danger of producing widespread damage resulting in a decerebrate status or other equally catastrophic conditions. In the author's experience suction is a much safer method by which to remove these tumors (Fig. 121). The soft or degenerated tumors may be removed directly. In the case of the firm tough tumors, usually containing many fibrillary astrocytes, which cannot be removed in this manner, there will usually be found a zone of softened tissue at the junction between the tumor and the cerebellar tissue. This can easily be removed by suction, literally shelling out the tumor. Either the solid portion of a cystic lesion or an entirely solid tumor may be removed in this manner.

Occasionally the tumor so isolated will prove too large to be removed intact through the defect in the cerebellar cortex and the bone (Bucy and Gustafson,[11] Case 1). Under such circumstances it is necessary to cut up the tumor into pieces in order to facilitate its removal. Again the surgeon should be warned to avoid those portions of the tumor attached directly to and invading the brain stem. Often after the cyst has been evacuated and the solid tumor removed the thin roof of the fourth ventricle will remain intact and be seen un-

dulating with the pulsations of the cerebrospinal fluid. In the author's opinion this is best left intact to avoid the possible seepage of blood from the tumor bed into the ventricular system. Some surgeons, however, prefer to open it to provide drainage of such blood and of fluid should the cyst re-form. Unfortunately, insufficient data are available to determine accurately which is the better procedure.

After the evacuation of a large cyst or removal of a large tumor the superior cerebellar surface sags downward, putting considerable pull upon the veins passing from the cerebellum to the overlying lateral sinus. On occasion the stretching of these veins will be so great that it is best to cut them between silver clips to prevent their being torn subsequently. In the author's experience, no bad effects have ever resulted from this procedure.

If an astrocytoma has been completely removed, the dura mater should be closed tightly to provide a firmer closure and to prevent the appearance, if possible, of the collections of cerebrospinal fluid which occasionally develop and which Doctor Cushing referred to as pseudomeningoceles. If, however, the extirpation has been incomplete, the dura mater should be left open to provide a decompression, although in view of the slowness with which these tumors recur and the rapidity with which the dura mater re-forms, this is of questionable value.

The author agrees with Cushing that two-stage operations are to be avoided in dealing with these tumors. The danger of introducing infection at the second operation as the result of some otherwise insignificant infection in the line of incision is not inconsiderable. Futhermore, as a result of hemorrhage and edema and the collapse of the cerebellum about the old operative field, it is often difficult to expose the tumor satisfactorily at a second operation performed shortly after the first.

*Hemangioblastomas* are usually simple to deal with, but when a large solid tumor is disclosed they present a difficult—often an impossible—problem. The cystic hemangioblastoma usually involves one cerebellar hemisphere. Unlike the astrocytomas, however, the solid nodule of tumor does not lie within the cyst deep in the region of the vermis but on or near the surface of the hemisphere often quite removed from the midline. The dark reddish tumor nodule may or may not be visible on the surface but its site is usually disclosed by the radiation of·large, dark-colored veins from that point (Fig. 123). Occasionally, however, the most careful search, even at autopsy, will not reveal the nodule of tumor in the wall of the cyst. At other times the nodule will be found in places difficult of access, as beneath the tentorium attached to the lateral sinus.

Unlike the cystic astrocytomas where the solid tumor is usually of considerable size, the hemangioblastic nodules are often not much larger than a pea. Careful search should always be made for the nodule as mere evacuation of the xanthochromic contents of the cystic cavity, leaving the nodule behind, leads to recurrence, often in a relatively short space of time (Cushing and Bailey[10]). Extirpation of these small nodules is rarely difficult. The vascular tributaries from it are occluded by silver clip or the coagulating current and the nodule is then removed without bleeding.

The larger tumors may prove very difficult or impossible to remove, particularly when there is no cystic cavity, evacuation of which will supply much needed room for exposure and exploration. This is particularly true of those which arise from the vascular area postrema in the region of the calamus scriptorius and those attached to the under surface of the tentorium and the lateral sinus. Here each case must be judged upon its own merits and the surgeon must decide whether to be content

with (1) a decompression leaving the tumor untouched, or (2) a partial extirpation, or (3) in rare instances, whether to attempt a complete removal.

Cushing[16] preferred to deal with these tumors by shrinking and desiccating them with the coagulating high-frequency cur-

even a small incision into one of these tumors may be associated with almost uncontrollable hemorrhage and that those tumors situated in the midline are usually intimately related to the brain stem and its blood supply. No attack upon one of these tumors should ever be made until
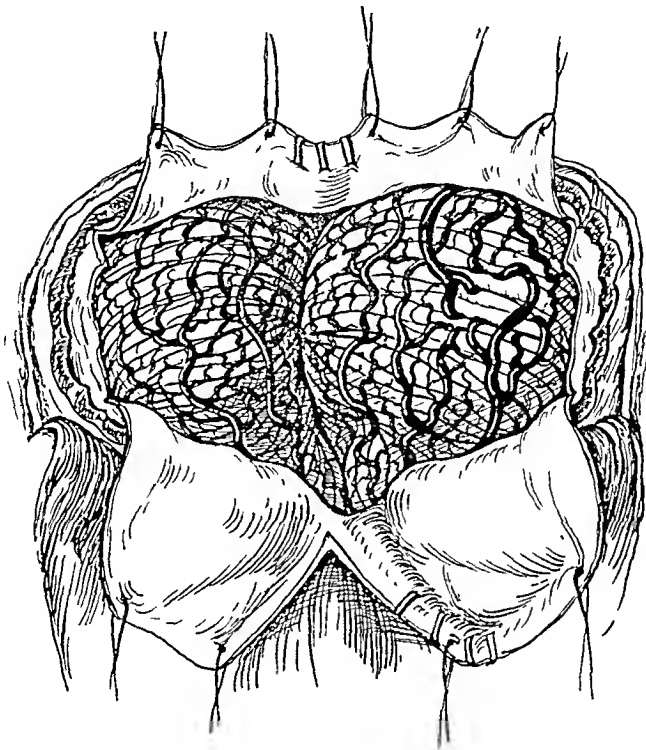


FIG. 123. Hemangioblastoma. The appearance of the cerebellum at operation. There is a hemangioblastic cyst in the right hemisphere. The site of the tumor·nodule is indicated by the point of convergence of the dilated veins. Note the herniation of the cerebellar tonsils through the foramen magnum.

rent. This method, though useful, is not without dangers, and the tyro is apt to literally burn holes in the vascular mass until it leaks like a sieve, instead of shrinking it. It is here also that pieces of muscle taken from the nuchal muscles or the patient's calf or fibrin foam will often prove most useful in controlling troublesome bleeding. The surgeon should always remember that

there is at hand a complete armamentarium for dealing with severe hemorrhage—electrical coagulating current, silver clips, muscle, fibrin foam, cotton packs. A vein should have been exposed and an intravenous injection of normal saline begun in order that a blood transfusion may be started with the least possible delay. Suitable blood should be available.

Occasionally the surgeon will be confronted with an apparently negative exploration—the expected tumor is not there. The widened vermis or the enlarged tense hemisphere with widened, flattened, slightly yellow folia are all absent, the cisterna magna appears to be of normal size, there is no undue tension in the posterior fossa. What should be done? A blunt exploring needle should be thrust into each cerebellar hemisphere while at the same time pressure is gently applied to the cerebellum Otherwise a cyst may be overlooked, for the pressure may be so reduced by ventricular puncture and the decompression that fluid will not flow forth spontaneously. In the absence of a cyst only experience will guide the surgeon in the proper interpretation of the resistance which the needle encounters If he suspects a deep-seated neoplasm a transverse incision should be made into the substance of the suspected hemisphere This will result in no demonstrable sequelae if carefully done. The greater part of the hemisphere can be removed, and so long as the dentate nucleus and its projection fibers into the superior cerebellar peduncle are not injured no permanent damage which is demonstrable clinically will be done The fourth ventricle should be carefully explored The cerebellar tonsils should be retracted laterally and a narrow ribbon retractor passed through the posterior medullary velum in the region of the foramen of Magendie. Gentle elevation upon this retractor will then expose most of the fourth ventricle to view. If necessary, a vertical incision can be made in the vermis and the ventricle explored up to the aqueduct of Sylvius.

Tumors in the posterior fossa which are productive of symptoms almost invariably distort the fourth ventricle, its walls or floor. If nothing is found in the ventricle to indicate the presence and location of a tumor some dye such as indigo carmine or phenolsulfonphthalein should be injected into the lateral ventricle. If there is no obstruction to the third ventricle or the aqueduct of Sylvius the dye should appear in the fourth ventricle almost instantly. The inferior surface of the cerebellum and the cerebellopontine angles should be explored. This will be readily accomplished by retracting the cerebellum medially and upward, care being taken not to tear the short, thin-walled veins which may be passing from the cerebellum to the lateral or petrosal sinuses.

Having determined that no tumor is present in the cerebellar fossa the decision must be made as to whether a decompression should be left or the dura mater should be tightly closed. If the error has been one of confusing some generalized encephalopathy such as lead intoxication (Bucy and Buchanan,[10] Haverfield, Bucy and Elonen[30]) or some inflammatory condition—"serious arachnoiditis" (?)—with a cerebellar tumor, a decompression had best be left. If, however, the tumor lies in the supratentorial midline—pineal tumor, craniopharyngioma, tumor of the hypothalamus—a suboccipital decompression is a dangerous thing (Grant[28]) and the dura mater should be tightly closed and continuous drainage of the laternal ventricles through a T-shaped needle or a catheter provided. This is one of the reasons why the dura mater should be opened originally with a simple curved incision as the common stellate incision is more difficult to close.

### OTHER CEREBELLAR EXPOSURES

**Midline Incision.** Occasionally the midline incision of Frazier[26] and Naffziger[36] may prove useful (Fig. 124). This procedure is simpler and less time-consuming than the procedure outlined above. It is adequate to explore the vermis, brain stem, and fourth ventricle, but does not adequately expose the cerebellar hemispheres (though it may be enlarged for that pur-

pose) and is too confining to allow of the extirpation of any but the most unusual cerebellar tumors. It is usually used when the surgeon anticipates finding an inoperable malignant tumor of the vermis or a

The midline incision should extend from about 4 cm. above the external occipital protuberance downward into the lower cervical region. The scalp is then dissected laterally from the deep muscular fascia.
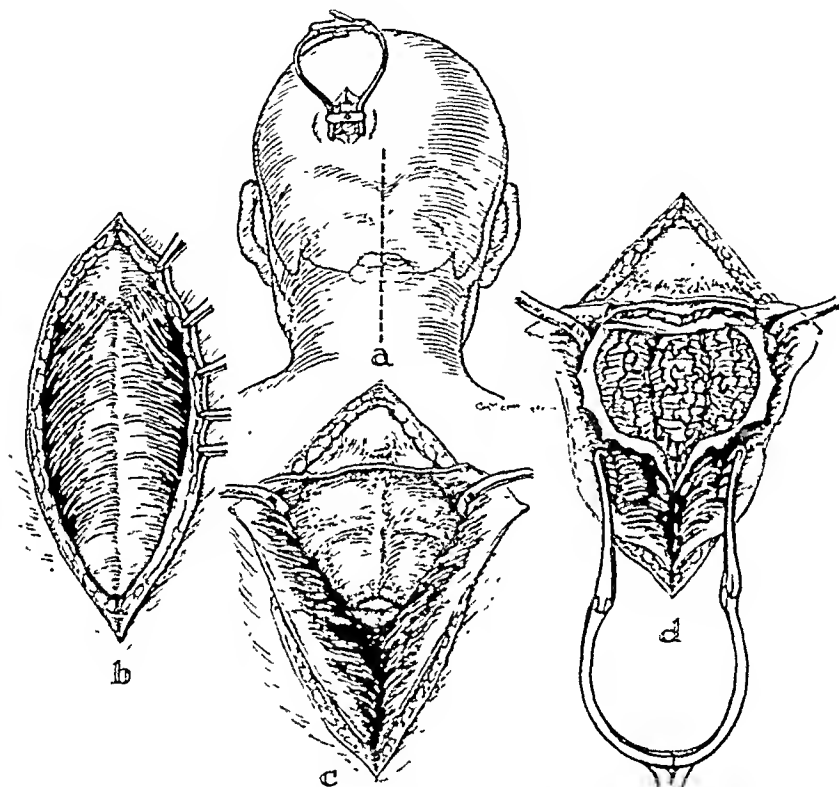


FIG. 124. Exposure of the cerebellum with a midline incision. (a) The left lateral ventricle has been punctured and the T-shaped needle is left in place. The proposed line of incision is indicated. (b) The skin is incised and retracted, exposing the neck muscles. (c) The nuchal muscles are incised transversely for a short distance on either side of the midline just below their attachment to the superior nuchal line and downward in the midline to expose the occipital bone and posterior arch of the atlas. (d) The bone over the midportion of the cerebellum is removed and the dura mater incised, exposing, in this case, a much widened vermis suggestive of a medulloblastoma. (Modified and redrawn after Naffziger.)

glioma of the brain stem, and merely wishes to confirm an uncertain diagnosis before denying the possibility of surgical extirpation and resorting to radiation therapy.

The neck muscles are incised transversely a short distance below their attachment to the superior nuchal line of the occipital bone and downward in the midline. They are then separated from the occipital bone
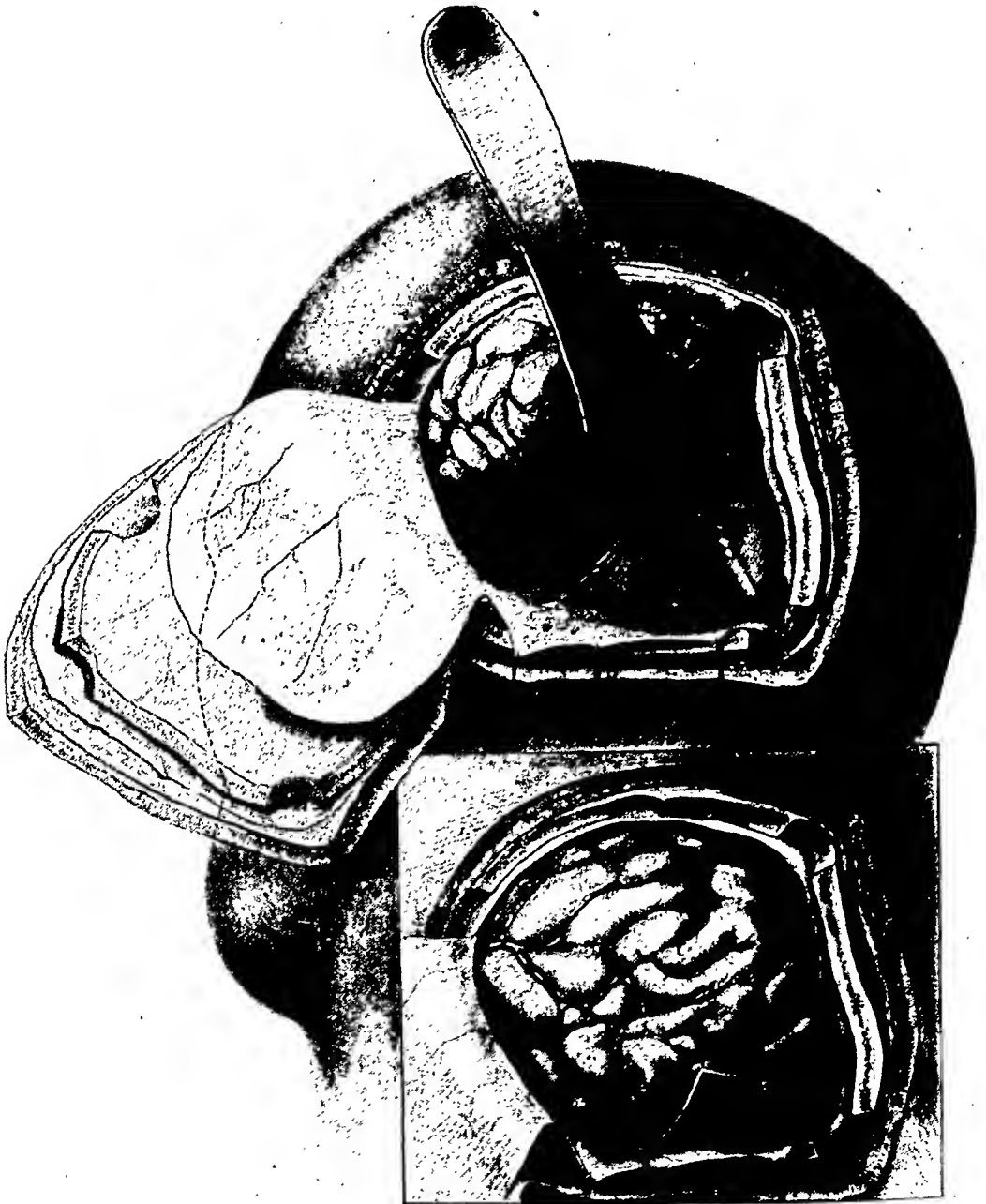
FIG. 125. An osteoplastic flap with its base in the temporal region and hinged on the temporal muscle and scalp has been turned downward and forward, exposing the occipital lobe. This lobe is then lifted upward and forward, exposing the tentorium. (After Naffziger.)

with a periosteal elevator and held laterally by self-retaining retractors of the "goiter" type. A trephine opening is then made in the occipital bone and one proceeds as outlined above.

Unilateral Incision. Although both the unilateral incision and the suboccipital osteoplastic flap of Bailey[4] are useful in approaching the bulbar nerves of one side and tumors of the eighth cranial nerve, they have no place in the treatment of intrinsic tumors of the cerebellum and brain stem.

Occipital Flap of Naffziger. This supratentorial approach of Naffziger[36] to the superior surface of the cerebellum and the cerebellopontine angle may on occasion prove useful. There is reason to believe that in the future we shall probably more often than in the past incise the tentorium into the incisura in order to relieve impaction of the uncinate gyrus through the incisura, compressing the mesencephalon and at present resulting in death in a few cases. This approach is admirably designed for that procedure, which, however, is not concerned with tumors of the cerebellum and brain stem. The operation should also provide an excellent exposure of the superior surface of the cerebellum. As the author has had little experience with it, the following is quoted directly from Naffziger[3] regarding the technical details.

The occipital flap is placed with the hinge just above the mastoid and the posterior part of the temporal fossa (Fig. 125). The anterior margin of the flap extends upward to the region of the longitudinal sinus and usually in front of the parietal eminence. The posterior margin is parallel to and immediately above the lateral sinus. The mesial margin is parallel to the longitudinal sinus and close to it. The patient is placed in the face-down "cerebellar" position. . . . With the dura exposed, ventricular puncture is performed and the ventricles well emptied. . . . The dura is opened usually with the hinge anteriorly. A varying number of veins will be found communicating with the lateral sinus from the margin of the occipital lobe. These are clipped or tied and divided. From the

dura over the petrous bone . . . two or three veins from the temporal lobe may likewise need ligating. The occipital lobe . . . is then elevated with a broad flat spatula. . . . The lifting of the occipital lobe upward exposes the tentorium, the attachment to the margin of the petrous bone, the floor of the middle fossa, and far forward to the posterior clinoids. . . . Incision is made in the tentorium (Fig. 126). The incision . . . is widened in all directions up to the petrous bone anteriorly to the sinus rectus mesially and to the lateral sinus. . . . With this opening the upper surface of the cerebellar lobe is exposed over a wide area. Retraction of it backward and laterally gives an exposure of the angle and the pons. . . .

This operation provides an internal decompression of the cerebellum, and an opening of the channels for cerebrospinal fluid around the midbrain. The dura mater of the tentorium is left open.

Closure and Dressing. The closure of the wound made for a cerebellar exploration differs in one important particular from the closure of other craniotomies. It is essential if leakage of cerebrospinal fluid, "pseudomeningocele," and cerebellar herniation are to be prevented that the nuchal muscles be firmly sutured. There is, of course, no osteoplastic flap to be replaced and thus aid in closure. The muscles and particularly the deep fascia immediately overlying them must be firmly and accurately sutured to the band of fascia and muscle which has been left attached to the superior nuchal line. In past years the author and his associates used catgut for this purpose, but the line of incision in the muscles occasionally broke open and this material gave rise to other difficulties which caused them to abandon its use for all purposes except the closure of potentially infected wounds. The ordinary iron-dyed fine silk popularized by Halsted and Cushing for the closure of wounds is often not strong enough for suture of the nuchal muscles. The author and his associates have accordingly adopted the use of No. 0 or No. 1 black braided silk, which has a

much greater tensile strength, though not a proportionately larger diameter. Once the muscle and fascia have been sutured the galea aponeurotica and scalp are closed in two layers with interrupted silk sutures abandon this part of the Halsted technic, but they soon returned to it, having demonstrated to their satisfaction that its value justified the bother and expense.) Silver foil helps to prevent superficial wound in-



FIG. 126. The tentorium is incised, exposing the cerebellum, which can be retracted to expose some of the cranial nerves and part of the brain stem. (After Naffziger )

In order to facilitate approximation of the muscles and scalp it is best to extend the head, a maneuver readily accomplished if the Bailey "cerebellar" head rest has been used.

Once the scalp is closed, silver foil is applied to the line of incision. (At one time the author and his associates attempted to fection, keeps the gauze dressings from adhering to the wound, and permits of exploration of the operative site while keeping the line of incision thoroughly sealed off and uncontaminated. A few pieces of gauze are applied and held in place by a gauze or elastic bandage. It is of the greatest importance that the bandage be not too

tight else ischemia of the scalp immediately above the incision, where arterial supply has already been greatly reduced by section of the occipital arteries, may result in an area of necrosis. Although the author and his associates have had considerable experience with starch crinoline bandages and plaster-of-paris splints, they are no longer in use in their Clinic in these cases and are quite unnecessary except in the very exceptional instance where the patient is irrational and uncooperative and additional protection is required. The starch crinoline bandage has one serious inherent danger—it shrinks as it dries. It should therefore be cut as soon as it has "set" and long before it has dried else areas of necrosis of the scalp may be produced. It should be watched carefully, thereafter, to be sure that it is not too tight.

## POSTOPERATIVE CARE

**Immediate Orders.** Immediately following the operation certain routine precautions should be instituted in order to insure adequate observation of the patient's condition by the nursing and resident surgical staff. The blood pressure, pulse, and respiration should be taken and recorded at 15- to 30-minute intervals until the patient regains consciousness. At that time, if the patient's condition is entirely satisfactory, the interval between these observations can be increased to an hour. At the same time careful note should be made of the patient's state of consciousness and of the direction of any change in it. These observations are particularly valuable in detecting two possible complications—hemorrhage and shock. Hemorrhage, which causes compression of the brain stem, heralds its development by inducing a deeper and deeper state of stupor and eventually coma, by diminishing the respiratory and pulse rates, and by a rising blood pressure. Shock, on the other hand, while also associated with increasing stupor, is evidenced

by a rapid feeble pulse, rapid respiration which may be gasping or shallow, and a falling blood pressure. These symptoms should be met with an immediate blood transfusion.

Following an operation in the cerebellar fossa the temperature should be taken at least every two hours. Occasionally following such an operation the patient will develop a hyperpyrexia and this should be combatted with sponging, electric fans, ice packs, etc., if the patient's life is to be saved.

It is also advisable to leave "P.R.N." orders for aspirin and acetophenetidin for the relief of pain. *Morphine should never be given.*

**Position.** The position of the patient in bed is of great importance. The patient should be placed and kept on his side to prevent pressure upon the back of his head. Otherwise pressure ischemia, particularly with children with large hydrocephalic heads, is apt to result in an area of necrosis at or just above the center of the wound, leakage of cerebrospinal fluid, and possibly intracranial infection. The unconscious patient, particularly if he is in danger of vomiting, should be placed in bed on his side with his head lowered. This helps to prevent the aspiration of vomitus with the likely sequel of aspiration pneumonia. This position also helps to combat possible sudden falls in blood pressure. As soon as the danger of aspiration has passed and if the blood pressure is at a satisfactory level the head of the bed should be elevated 45° to 60°. This lowers the intracranial venous pressure and reduces the danger of postoperative venous oozing.

**Fluids.** It is important to take into account the facts that fluids have been denied the patient for hours prior to the operation, that he has been unconscious for hours during the operation, and may be for some time thereafter, and that he has lost considerable fluid and salt by per-

spiration and by loss of blood during the operation. If this entire deficiency has not been corrected by the administration of fluids during the operation it should be afterwards. If the immediate need for fluids is not great, normal saline can be administered by hypodermoclysis, or in the event of somewhat more urgent need 10 per cent glucose in normal saline may be given intravenously. However, if the need is very urgent, if the blood pressure is falling or is low, reliance should not be placed upon the glucose-saline solution except as a temporary measure to be utilized while blood is being obtained for a transfusion and to establish and have in operation the entire apparatus for the administration of blood. One physician should begin the administration of glucose-saline solution while another obtains the blood. For one man to attempt the entire operation may result in an undue loss of time. There should be no hesitancy about administering a transfusion of blood in these cases, and when in doubt it is best to transfuse. Even a short delay may result in an unnecessary death (Bailey, Buchanan and Bucy,[6] Cases 20, 31, and 84). Reactions to blood transfusions are practically nonexistent when the bloods are carefully typed and cross matched, when the blood is carefully administered by the citrate method, and *when the apparatus is clean.* Practically all reactions result from the use of dirty rubber tubing, tubing in which blood or other solutions have been allowed to dry.

Ringer's solution is never used for intravenous administration on the service of the author and his associates as it cannot be safely mixed with blood, for a precipitate of calcium citrate will form and the blood will coagulate. Therefore, if it is never used, there will be no danger of this incompatible mixture ever being made. Solutions of glucose in distilled water should be alternated with glucose in normal saline in order to avoid overloading the patient with sodium chloride.

**Food.** Occasionally these patients will experience difficulty in swallowing and under such circumstances food and fluids by mouth should be withheld to prevent their aspiration. When this is of but a short duration the parenteral administration of fluids as described above will suffice. However, when it persists for days, nasal feedings, using properly balanced liquid mixtures of milk, cream, eggs, glucose, vitamins, etc., must be resorted to.

**Lumbar and Ventricular Puncture.** Not infrequently, because of intracranial hypertension, headache, pyrexia, persistent stupor, etc., it will be necessary to remove cerebrospinal fluid in order to reduce the pressure and/or combat the symptoms of subarachnoid hemorrhage. When reduction in pressure is all that is desired, ventricular puncture is preferable. When, however, subarachnoid hemorrhage is at fault spinal puncture must be done. Obviously drainage of cerebrospinal fluid through a lumbar puncture can remove but a very small percentage of the blood present in the subarachnoid space. To speak of washing out this blood is nonsense. Yet no one can deny that a lumbar puncture often dramatically abolishes the headache, stiff neck, nausea and vomiting, stupor, and pyrexia of such cases even though the mechanism of this relief remains obscure.

In contrast with some other clinics it has never been the author's policy to make those punctures, spinal or ventricular, either routinely or frequently. Nor, in the author's opinion, is there any advantage to be gained by such a blind routine procedure. However, when indicated, such punctures should be performed without hesitation. When the intracranial hypertension is at all persistent or when the relief obtained by puncture is only temporary, a search for underlying causes should be made. If no indications for more drastic in-

tervention are found, a T-shaped needle should be inserted into the lateral ventricle and left in place to provide continuous drainage until the symptoms have subsided. When a T-shaped needle has been inserted, the patient should be kept in bed with his head lowered in order to maintain a constant outward flow of fluid and prevent the ingress of infectious material. The wound should be dressed twice a day with dressings soaked in 80 per cent alcohol and adequate amounts of fluids should be supplied the patient. To attempt to combat these symptoms by the restriction of fluids and the use of dehydrating agents such as hypertonic solutions and magnesium-sulfate purges is to invite serious trouble from dehydration and acidosis in patients in whom those same complications are to be avoided.

## Complications

Mention has already been made of some of the more common complications of a cerebellar exploration—delayed shock, aspiration, difficulty in swallowing, pressure necrosis of the scalp, leakage of cerebrospinal fluid, and infection. The treatment of some and prevention of others has been discussed. But somewhat fuller consideration of some is warranted.

**Leakage of Cerebrospinal Fluid.** Undoubtedly the development of a cerebrospinal-fluid fistula is a serious complication but not so grave as has often been thought if proper treatment is instituted (Bucy[9]). As soon as the discharge of cerebrospinal fluid from a wound is detected the patient should be confined to bed with the body tilted with the head downward. This encourages the free flow of fluid, continually washes the wound clean, and prevents the entrance of infection. The scalp about the fistula should be shaved, and dressings saturated with 80 per cent alcohol should be applied to the wound and changed two or three times a day. Fluids should be forced

to 3,000 or 4,000 cc. at least. This regimen should be continued until the drainage of fluid ceases spontaneously and the wound heals. In many cases where the drainage of fluid is not desired it is best to re-suture the wound promptly.

**Infection.** Fortunately, infection of the wound is a rare complication of cranial surgery. It most commonly develops following the re-exploration of the wound because of suspected hemorrhage or to complete the extirpation of a tumor. Infection is most apt to occur when the re-exploration takes place a few days after the first operation. Therefore, a wound should never be explored for suspected hemorrhage unless one is reasonably certain of that diagnosis and unless such exploration is imperative. Two-stage operations should be avoided for the same reason. If a second operation is necessary it should, if possible, be delayed until after all cutaneous sutures have been removed and until the scalp has been able to destroy or lessen the virulence of the infectious organisms which were probably introduced into the wound at the first operation. When possible, 10 to 14 days should be allowed, and longer periods are safer. Even when re-exploration has been undertaken, evidence of infection, even though mild, in the old incision is an absolute contraindication to proceeding further.

As soon as evidence of any infection in the wound appears after any operation one of the sulfonamides by mouth or intravenously or penicillin will be started at once. In addition the wound should be opened generously—sufficient to allow free drainage and to allow cerebrospinal fluid to wash the wound, if one is fortunate enough to have it do so. Those general measures applied in all cases of infection, rest, relief of pain, fluids, etc., should, of course, be fully utilized.

**Vomiting.** Occasionally, particularly following an operation upon an ependym-

that on occasion these sarcomas respond much better than do the medulloblastomas, while on other occasions, particularly in young children, they do not respond so well (Bailey, Buchanan and Bucy[6]).

On occasion children suffering from gliomas of the brain stem seem to improve following treatment with the x-rays. The improvement is of short duration, however, and death soon follows in most cases.

The vascularity of papillomas of the choroid plexus may be so effectively reduced by radiation that a tumor that could not possibly be removed when first exposed may be subsequently dealt with (van Wagenen[41]) though the ultimate outlook in these cases is often poor.

The efficacy of radiation therapy in hemangioblastomas has never been established. Dandy[18] says that treatment with the x-rays or radium is useless but supplies no factual data. In cases in which complete extirpation is not possible it will probably be the better part of wisdom to expose the cerebellar region thoroughly to the x-rays until the value of this form of treatment has been accurately assessed.

It is now well established that the x-rays are of no value in treating cerebellar astrocytomas or ependymomas of the fourth ventricle and there is little reason to expect beneficial effects in cases of those rarer tumors, polar spongioblastomas, astroblastomas, dermoids, epidermoids, and teratomas.

Unfortunately, radiation therapy has been of permanent help to but few sufferers from tumors in the cerebellar fossa. Undoubtedly this form of treatment has been applied much too widely and blindly in the past. Its use in the future should be restricted to those cases in which its value has been established or to those in which its value is as yet unknown and where we are still seeking definite information—principally the hemangioblastomas.

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# 13

# Vascular Anomalies of Brain

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Arterial aneurysms, although often congenital (and hence vascular anomalies) and traumatic arteriovenous fistulae are considered in Chapter 11. This chapter will be concerned with those lesions which are composed of multiple anomalous vessels, whether wholly venous or arteriovenous, and which are, in the broader sense, tumors. They are not true neoplasms, however, and must not be confused with the "hemangioblastomas." The latter are new growths composed of endothelial elements, whereas the angiomatous malformations and arteriovenous aneurysms are made up of well-developed, if anomalous, vessels.

Not many years ago this chapter would have been of little, if any, practical importance, and its inclusion would have been of questionable wisdom. The vascular lesions of the type to be discussed here were considered inoperable by the most intrepid neurosurgeons and most of the few attempts at their surgical eradication resulted disastrously. In recent years, however, newer technics and particularly newer hemostatic methods have altered this situation and a number of the large vascular malformations have been successfully removed. Nevertheless, they still remain exceedingly formidable lesions. Radical surgical attack upon them is to be made only upon serious and pressing clinical indications and with a clear understanding of and preparation for the difficulties to be encountered.

## PATHOLOGY

There has been no unanimity of opinion regarding the nature and classification of the intracranial vascular anomalies except for general agreement as to their congenital origin. Their capacity to change and to extend themselves, by formation of new vessels or development of arteriovenous communications, has long been a controversial subject and is as yet an uncertain factor. However, their growth by dilatation, particularly of huge distended venous channels, is beyond question.

All of these lesions have an extensive arterial supply, but there is strong evidence that many of them do not have direct arteriovenous communications. The proportion of venous and arterial elements varies in each lesion and has led to many attempts at classification and a rather confused nomenclature. At one extreme are the angiomatous varices, composed of one or many tortuous, distended veins, whose arterial supply enters by devious and multiple routes; at the other, the aneurysmal varices, whose tangled masses of worm-like arteries are drained through relatively few enlarged veins. Between the extremes are innumerable variants. Cushing and Bailey divided them into two great groups—"angioma venosum" and "angioma arteriale." Dandy, rather arbitrarily, considers them all to be "arteriovenous aneurysms." Probably the term "angiomatous malformation" is the least controversial, the most

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reason, convulsions are the most common clinical manifestation. The seizures may be focal or generalized, depending upon the location of the lesion.

Since the lesions are congenital, convulsions usually appear early in life, but the diagnosis of idiopathic epilepsy may obscure the true state of affairs for many years and a large angiomatous lesion may not be discovered until middle life or later.

Evidence of increased intracranial pres-

Angiomatous malformations may involve any of the intracranial vessels, but there seem to be certain sites of predilection. The "arterial varices" are more common over the parasagittal portion of the cerebral convexities. A peculiar worm-like calcified angioma has been reported several times as occurring on the medial surface of the occipital lobe and the roentgenograms in these cases are almost identical (cf. Fig. 127 and Cushing and Bailey, Fig. 12, p.



Fig. 128. Roentgenograms of a vascular malformation deep in temporoparietal region. Thin lines of calcification (arrows) were sole evidence of cause of patient's convulsions.

sure is rare, since the growth of the lesion is extremely slow and compensation is adequate. Many patients do not even have headaches and papilledema is quite rare.

Focal disturbance of neurologic function is very variable and may not be present at all. Convulsions may be of the jacksonian type if the lesion is frontoparietal in location, but generalized seizures are more common. Impairment of motor or sensory function is unusual and such symptoms as diplopia and unilateral exophthalmos are usually dependent upon the retro-orbital location of the lesion.

25 and Fig. 13, p. 26). However, it is significant that three successive cases operated upon by the author received their blood supplies through the posterior, middle, and anterior cerebral arteries, respectively.

A bruit is present only when there are large arteriovenous communications. It is the characteristic rough or blowing continuous murmur with systolic accentuation which fades off gradually into the background of continuous sound. Even with large arteriovenous openings, no bruit may be audible.

FIG. 129. Illustrations of an enormous vascular anomaly. Only symptoms were convulsions. (*Above*) Roentgenogram showing thin lines of calcification in greatly dilated venous channel. (*Below*) Photograph of specimen. Great sac below is a single vein. Smaller mass above shows other distended veins; its intermediate portion was composed of tangled arteries.

Enlargement of vessels of the scalp and diploë is quite rare and there is usually no other telltale evidence of collateral channels.

One important manifestation, when present, is the telangiectatic nevus of the skin elsewhere on the body and particularly on the face—the so-called "trigeminal telangiectasis." These congenital vascular anomalies of the skin may be the only evidence leading to the suspicion that a patient with convulsions has an intracranial vascular anomaly as well.

By far the most reliable diagnostic evidence in most cases comes from roentgenography. The high percentage of calcification leads to relatively easy recognition of the lesion in most instances. The opaque shadows usually present a characteristic tortuous pattern which could be present only in vascular walls (Figs. 127, 128). In the case of greatly distended venous channels, however, there may be very thin lines of calcification around large areas, giving the appearance of a multilocular cyst (Fig. 129).

The cerebrospinal-fluid pressure is usually normal and rarely greatly elevated. Since the lesions almost never rupture or leak, bloody fluid is seldom encountered. The protein content of the fluid may be normal or moderately elevated.

Pneumographic studies, angiography and electro-encephalography should yield valuable information in these cases, but information from these sources has been as yet too scanty for final evaluation.

## TREATMENT

There is some evidence that irradiation therapy is efficacious in reducing the size of the venous malformations. Such therapy should be employed, however, only if there is evidence of widespread, bilateral, or multiple lesions, or if the diagnosis is made in the absence of severe or incapacitating symptoms.

In the author's opinion, all patients with a localized angiomatous malformation who have frequent convulsions, focal neurologic signs, or other severe symptoms should receive radical surgical treatment. Operations for these lesions are formidable procedures, but their removal is now by no means attended with prohibitive risk and it offers the only real hope of relief of symptoms.

Simple surgical decompression is to be condemned except in those rare instances in which increased pressure accompanies multiple or widespread lesions.

### PRELIMINARY PRECAUTIONS

Once exposed, these lesions must be dealt with as the circumstances and the surgeon's judgment dictate. It is well, however, for him to anticipate and prepare for difficulties which are likely to arise.

The author has never considered it necessary to expose the internal carotid artery as a preliminary procedure, but this precaution is certainly worthy of consideration in patients with large arteriovenous anomalies. Dandy has ligated the internal carotid in two cases of this type as the principal therapeutic procedure (without radical removal of the lesion). Both patients were benefited.

If carotid ligation is to be employed, the efficacy of the collateral circulation must be determined. Ligation of the internal carotid artery should be carried out (or planned) only if digital compression of the artery is tolerated without symptoms for a minimum of ten minutes. If contralateral sensory or motor phenomena occur within this period, the operation should be postponed, the patient taught to compress his own carotid artery, and this procedure carried out for increasing periods many times daily until no symptoms occur.

Whether or not the carotid artery is to be exposed, a needle should be placed in the greater saphenous vein just above the ankle before the operation is begun and

large quantities of blood for transfusion should be available.

OPERATIVE PROCEDURE

In no operation is adequate exposure more important Control of vascular con-

of the arch of the atlas and, if abnormal vessels extend downward into the spinal canal, of additional laminae as well.

Since most of these lesions arise from the pial vessels or their penetrating branches, there are rarely any large dural
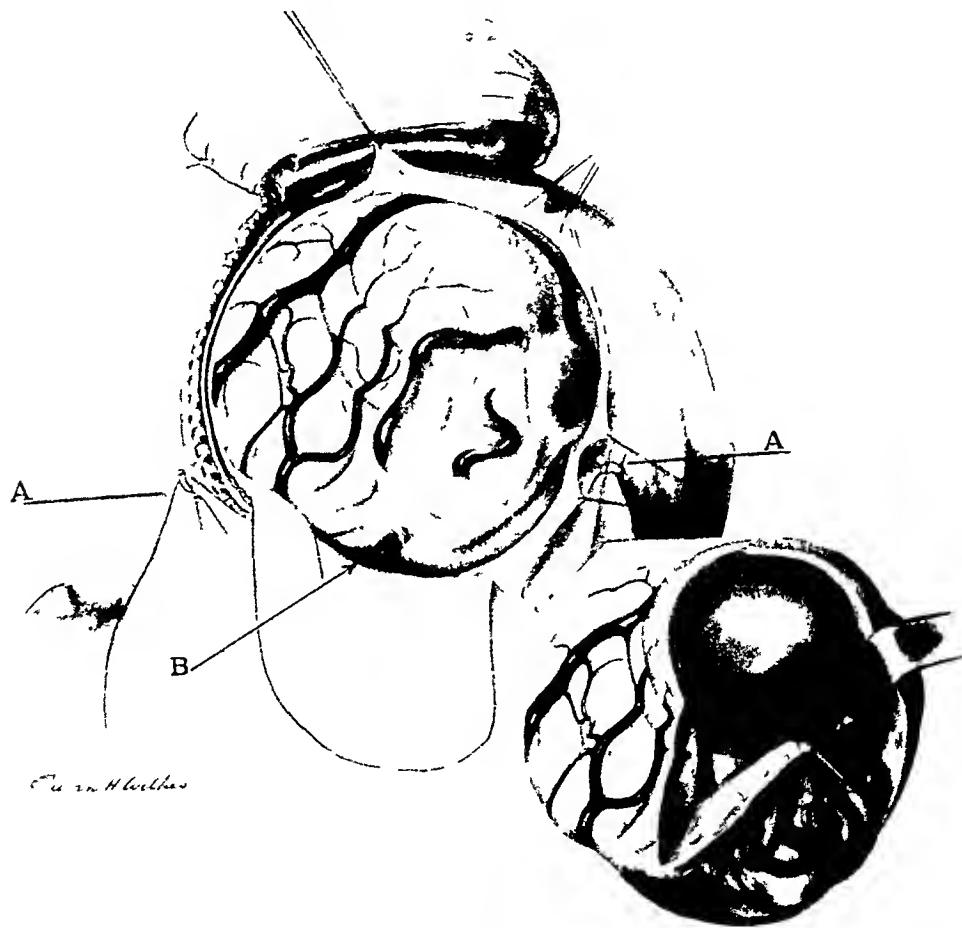


FIG. 130. Drawing made at operation on patient shown in Fig. 129. Line A-A indicates midline, showing displaced sinus with principal draining vein (B). A thin layer of cortex overlay great venous sac. Compare inset with Fig. 129.

nections well beyond the periphery of the lesion is often essential. For lesions of the cerebral hemispheres, a large osteoplastic flap should be so planned as to take care of any such contingency; for those of the posterior fossa, a wide suboccipital craniectomy should be accompanied by removal

communications Nevertheless, the dura must be opened cautiously for fear, not only of tearing such possible connections, but also of rupturing underlying thin-walled vessels.

If the lesion presents on the surface, as is usually the case, the surgeon must next

evaluate the vascular picture. There are often large subcortical extensions beyond the exposed portion of the lesion.

An effort should first be made to determine whether the principal arterial supply of the lesion enters through accessible vessels and can be controlled. In some cases this will be relatively simple, in most it will be difficult, and in a few it may be impossible.

It is at this time and based largely upon this point that the surgeon's judgment must determine whether to attempt the radical extirpation of the lesion or to discontinue the procedure entirely. In dealing with angiomatous malformations, halfway measures are not only of no benefit but are fraught with danger of disaster.

If the lesion is to be removed, cautious control of its arterial supply should be the first step. Occlusion of the great cerebral trunks is to be avoided if possible, but entering arteries should be secured well away from the actual vessels composing the anomaly. It may be necessary, as a preliminary step, to incise the cortex over undermining portions of the lesion (Fig. 130). Even this is difficult because of many distended vascular connections and every move must be made with caution. Even when every care is taken, deep and unexpected vessels may cause great difficulty.

For control of relatively large arteries, electrocoagulation alone may be inadequate and may present a risk of late re-opening of the vessel. Silver clips or, in some locations, fine silk suture ligatures are preferable.

When all accessible arterial connections have been secured, the great veins leading from the surface of the lesion should be similarly attacked. In some cases, it may thus be possible successfully to control the principal vascular connections by a relatively superficial primary approach. In such instances, cautious dissection and enucleation of the lesion may be carried out,

each additional vessel being dealt with as encountered.

All too frequently, however, the procedure is not so simple. In the presence of a patent deep arterial supply, obstruction of one or more of the great veins may result in rupture of the thin-walled structure and sudden profuse hemorrhage. A direct attack upon such hemorrhage is often ineffective.
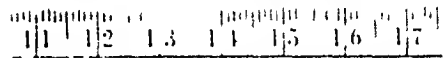


FIG. 131. Amputated occipital pole from patient shown in Fig. 127. Tortuous vessels lie in medial surface (discolored area at right).

Coagulation and clips fail because of the size of the tear in the vessel; sutures or clamps simply serve to tear additional thin-walled vascular channels.

Thus the only remaining course may be the rapid enucleation of the mass, until the deep arterial supply has been met and controlled. This may be done with malleable aluminum retractors, but often the gentle dissecting finger is most effective and offers the advantage of palpation of entering vessels as they are met.

Meanwhile, powerful suction, directed through moist cotton which is gently but

firmly pressed upon the bleeding area, will preserve a clear field. Future experience may demonstrate here a field of usefulness for thrombin applied through the medium of fibrin foam or other absorbable sponge.

When the mass is finally removed, bleeding in its bed is controlled as in the case of any other tumor. It is at this time, too, that transfusion should be begun, if the hemorrhage has been severe or the blood pressure has fallen sharply. Whole blood, rather than plasma, should be given.

When the lesion lies wholly beneath the surface, as in those arising from the deep middle cerebral connections, the problem may be even more difficult. Cortical incision down to the surface of the lesion may itself be a bloody and hazardous but a necessary procedure. Adequate exposure is essential and may sometimes necessitate excision of a cylinder of cerebral tissue. Here again, control of the arterial supply must be obtained, if possible, but rapid removal, dealing with vessels as they are exposed, may be necessary.

In dealing with some angiomatous malformations, radical lobectomy beyond the limits of the lesion may be preferable. This is particularly true of the varices of the medial surface of the occipital lobe (Fig. 127). By careful control of the branches of the posterior cerebral artery and of the veins emptying into the lateral and longitudinal sinuses and downward toward the corpus callosum, amputation of the occipital pole may be carried out as a well-nigh bloodless procedure (Fig. 131).

## RESULTS OF SURGICAL TREATMENT

No sweeping statement regarding survival after removal of the angiomatous malformations can be made, since the number of reported cases is too small. The three patients in whom radical extirpation of such lesions was carried out by the author are all alive and without serious neurologic deficit.

Two of these three patients have been relieved of the convulsions which constituted their principal preoperative complaint. The third still has an occasional seizure. In the literature, most of the reported cases have been treated by less radical procedures (carotid ligations, decompressions, radiation therapy) and most have continued to have convulsions.

It is the author's considered opinion that most patients with these formidable lesions are amenable to and should be given the benefit of radical surgical removal. Nevertheless, the surgeon must be able to recognize the limits of such possibilities and must have the courage to withdraw when faced with lesions beyond these limitations.

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SECTION THREE

# CRANIAL AND INTRACRANIAL SURGERY

## CRANIAL NERVE DISORDERS, INVOLUNTARY MOVEMENTS AND EPILEPSY

# 14

# Surgery of Disorders of Cranial Nerves

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### AND

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The first, third, fourth, and sixth pairs of cranial nerves are affected by trauma, infections, toxins, tumors, and aneurysms. Tumors of the cranial nerves are discussed in Chapter 9, injuries in Chapter 3. There are no intrinsic diseases of these four pairs of cranial nerves, other than neoplasia, which have been treated surgically.

## OPTOCHIASMATIC ARACHNOIDITIS

The optic or second pair of cranial nerves is rarely exposed surgically except when these nerves are affected by tumors or aneurysms. An infrequent indication for surgical exposure of these nerves in their intracranial course is arachnoiditis which threatens loss of vision. Low-grade meningitis may result in a hyperplastic thickening of the meninges about the chiasm and nerves or the cisterna chiasmatis may become greatly distended with xanthochromic fluid. The result in either case is progressive loss of vision which may result in complete blindness. The diagnosis should be suspected if the visual fields are bizarre and inconsistent with pituitary tumor. In selected cases, surgical intervention is indicated to preserve the remaining vision. Actual improvement in vision frequently follows operation.

The optic chiasm and nerves are exposed by the same approach used for removal of pituitary tumors (Chapter 11). The balance of the procedure consists in opening the cystic cisterna, if present, and in a painstaking removal by blunt and sharp dissection of the adhesions constricting the optic chiasm and nerves (Fig. 132). Obviously, this must be done with as little traction as possible on these delicate structures. After the chiasm and nerves have been freed from the adhesions, the lighted retractor is removed, permitting· the frontal lobe to fall back into its normal position. The closure of the dura, skull, and scalp is carried out as described in Chapter 1.

## ORBITAL DECOMPRESSION FOR PROGRESSIVE EXOPHTHALMOS

Another operation during which the optic nerves are exposed is the Naffziger procedure for malignant exophthalmos. In certain cases of hyperthyroidism the exophthalmos continues to progress in spite of thyroidectomy and return of the metabolic rate to normal. Eventually, the lids fail to cover the protruding eyes and ulcerative keratitis develops. The end-result is apt to be loss of both globes because of infection; meningitis or thrombophlebitis of the cavernous sinus may follow. Hence the expression malignant exophthalmos.

Patients whose eyesight is threatened by optic atrophy or corneal damage secondary to progressive exophthalmos should be operated on in the following manner: Under local or general anesthesia a coronal incision is made just behind the hairline of the forehead. The scalp flap is reflected forward, and a unilateral bone flap is fashioned as described in Chapter 11 on the removal of pituitary tumors. The frontal lobe and its dural covering are elevated with a spatula or lighted retractor until a
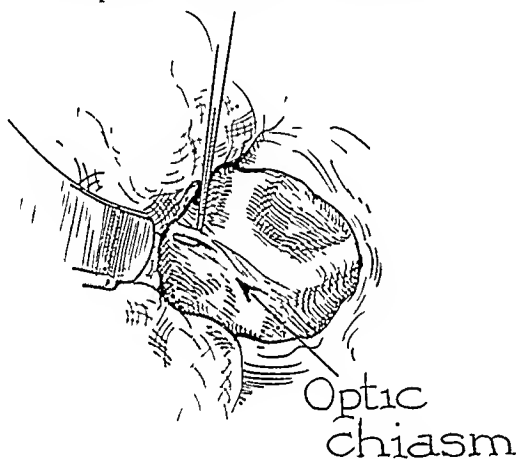


FIG. 132. Optochiasmatic arachnoiditis. Adhesive bands constricting optic nerves and chiasm are removed with a right-angle knife or small scissors.

good exposure is obtained of the orbital roof, the sphenoid wing, and the base of the anterior clinoid process. The roof of the orbit is opened and partially removed. Great care must be taken to avoid opening the frontal and ethmoidal air cells which extend into the orbital plate. Preoperative x-rays should be made so that the size of these sinuses is known. The removal of bone is carried posteriorly until the superior orbital fissure is opened. Of great importance is the removal of bone from the lateral wall of the orbit. This wall is formed by the greater wing of the sphenoid bone posteriorly and by the maxilla anteriorly. The bone removal should be carried to the inferior orbital fissure. This extensive removal of bone permits the orbital contents to bulge into the temporal fossa as well as into the cranial cavity. Finally, the optic canal should be unroofed, particularly if choked disks or failing vision exists. The final step is to open widely the orbital fascia in a stellate manner. Care should be taken to avoid the supra-orbital branch of the fifth nerve which lies on the orbital fascia. As little bleeding is encountered in the procedure the frontal lobe and its dural covering can be permitted to fall back into place as soon as the orbital fascia has been opened. The other orbit can be unroofed at the same operation by reflecting another bone flap, leaving a bridge of bone at the midline.

Postoperatively, there is immediate improvement in the exophthalmos, but after 24 hours the globes again begin to protrude because of increased intracranial and intra-orbital pressure. At this stage the care of the eyes becomes a serious problem. Boric ointment, irrigations, and goggles are required. A possible solution to the problem of postoperative protrusion of the eyes is as follows: Immediately following the craniotomy the eyelids are closed with sutures and pressure bandages are applied and left in place for five days. Spinal drainage is performed after operation and repeated daily for several days.

## COMPRESSION OF OPTIC NERVE FOLLOWING SKULL FRACTURE

Fractures of the base of the skull which extend into the optic foramen may destroy the optic nerve, producing immediate blindness of the eye on the side of the lesion. Surgical decompression of the nerve in such a case is almost certain to be a futile procedure because the optic nerve does not regenerate after it has been crushed. However, in occasional cases of fracture through the optic foramen, loss of vision may develop gradually a month or two

after the injury, indicating that the nerve is compressed by the formation of callus. Such a case was reported by Lillie and Adson. Surgical treatment in similar cases should be carried out promptly and should consist of an adequate removal of the roof of the optic canal.

## TRIGEMINAL NEURALGIA OR TRIGEMINAL TIC DOULOUREUX

Trigeminal neuralgia or trigeminal tic douloureux is referred to by various other names, including major trigeminal neuralgia and trifacial neuralgia. It is characterized by brief attacks of excruciating pain in the face.

### ETIOLOGY

Since the cause of trigeminal neuralgia is not known, the disease must be classified as idiopathic. It is neither familial nor hereditary. Infections of the teeth and accessory nasal sinuses bear no relationship to trigeminal neuralgia.

There is some evidence which indicates that trigeminal neuralgia may be a special form of thalamic syndrome. Arterial loops and small tumors lying in contact with the sensory root of the fifth nerve are found often enough in trigeminal neuralgia to indicate that they may occasionally be the cause. Only a small proportion of patients with tic douloureux have multiple sclerosis, migraine, or syphilis, but many have arteriosclerosis with or without hypertension.

### AGE OF ONSET, SEX, INCIDENCE, AND LOCATION

Trigeminal neuralgia is rarely encountered in patients less than 35 years of age. In the majority of cases the onset of the disease occurs between the ages of 40 and 60. However, it may occur at any age. The authors have operated upon quite a number of patients under 20. Slightly more than half of the cases reported in the literature have been in women. The incidence of the disease in the general population is not great. Approximately 4,000 patients are treated each year in the United States by intracranial section of the sensory root of the nerve.

For unknown reasons the right side of the face is affected more often than the left. Bilateral trigeminal neuralgia occurs in less than 5 per cent of the cases. In some patients the pain may be limited to the distribution of one of the peripheral branches of the fifth cranial nerve, such as the supra-orbital or infra-orbital. Of the three divisions of the gasserian ganglion, the third or mandibular is affected slightly more often than the second or maxillary. Only occasionally is the pain found solely in the first or ophthalmic division. The pain may spread from one division to another but never involves the first and third divisions without involving the second. In about 15 per cent of the cases all three divisions are involved at the time of operation.

### SYMPTOMS AND SIGNS

The first manifestation of trigeminal neuralgia is a lightning-like pain in some part of the face. There is no warning and no apparent cause. The paroxysm usually lasts for only a few seconds, but it may last for several minutes. Observation or careful questioning of the patients with prolonged attacks usually discloses that the seizure is made up of a series of pains. The pain starts like a bullet and stops just as suddenly. There may be some burning, aching, or hyperesthesia after the intense pain ceases. A few patients have more or less constant dull pain between the paroxysms of shooting pain.

Rarely is a patient able to conceal his suffering from observers. He ceases to talk or to listen. There may be violent movements of the face or jaw which are largely

voluntary. The hand may be used to rub, pinch, or press the face. The victim may clench his fists, close the eyes tightly, or rock back and forth. Watering of the eye on the side of the pain is frequent.

Although there is often subjective hyperesthesia of the face immediately after the attack, there is never any sensory loss on the skin or mucous membrane. The



FIG. 133. Diagram of sensory areas of head including the three divisions of the fifth nerve. Vagus (X) supplies skin of posterior part of external auditory meatus and back of ear. Tympanic membrane receives some sensory fibers from glossopharyngeal nerve (IX).

motor division of the fifth nerve is never involved. The one important finding is a trigger zone. This is a small area on the cheek, at the angle of the mouth, on the lip, or at the side of the nose. Touching the trigger zone during chewing or laughing may instigate an attack, and even a breeze may start the dreaded pain. During periods of remission the trigger zone disappears. With rare exceptions these patients experience spontaneous relief lasting for weeks or months. In most cases remissions become

shorter until the attacks are occurring daily or many times daily. As the disease progresses there seems to be an increase in the intensity of the pain, although this can perhaps be explained on the basis of decreasing stamina.

The pain is always strictly limited to the anatomic distribution of one or more divisions or peripheral branches of the fifth nerve (Fig. 133). Never does the pain cross the midline of the face. Never does it radiate to the neck. The disease is occasionally bilateral, but these unhappy persons are usually spared attacks on both sides at the same moment.

A characteristic feature of trigeminal neuralgia is the patient's method of demonstrating the location of the pain. He points with a finger to the site of the pain but does not actually touch the skin except during a remission. On the other hand the patient with nasal sinus disease or painful teeth manipulates or handles the part without hesitation. Patients with tic douloureux often talk without moving the lips and with a minimal movement of the tongue. The muscles of expression are moved as little as possible during conversation, and there is little or no smiling. The patient is sometimes willing to demonstrate an attack to the examiner by stimulating the trigger zone, but he thoroughly resents repeating the demonstration. Immediately after an attack the eye may appear red and the cheek may be flushed.

### DIAGNOSIS

The diagnosis of trigeminal neuralgia depends almost entirely on the history and the patient's description of the pain. Witnessing an attack settles any doubt that may arise in the examiner's mind. The pain of tic douloureux is without doubt the most excruciating pain to which human beings are subjected.

One objective method of making the diagnosis of trigeminal neuralgia is to pro-

duce a remission by alcoholic injection of the involved division or branch of the nerve. However, this method is not applicable to all cases and is required only in an atypical case.

### DIFFERENTIAL DIAGNOSIS

Trigeminal neuralgia must be differentiated from other types of pain which occur more or less in the area of distribution of the fifth cranial nerve. Although much of the pain resulting from diseased teeth and diseased nasal sinuses is carried over the fifth nerve, these pains in no way resemble the pain of trigeminal neuralgia; they are throbbing or steady and persist for hours. The onset is gradual and the pain departs slowly. Rarely is there any resemblance between trigeminal tic douloureux and headache, migraine, or pain due to tumors and cysts of the face and jaws. The pain of herpes zoster of the face may bear a resemblance to trigeminal neuralgia during the acute stage, but the appearance of the vesicles soon establishes the correct diagnosis.

Tumors and other lesions of the cerebellopontile angle and tumors of the gasserian ganglion may produce pain in the face which closely resembles or is identical with attacks of trigeminal neuralgia. Partial loss of the fifth-nerve function, which usually occurs with such tumors, differentiates these conditions from trigeminal neuralgia. Areas of anesthesia develop on the face, and the corneal reflex disappears on the affected side. Involvement of the motor division of the nerve may in time produce weakness of the muscles of mastication.

Glossopharyngeal tic douloureux is easily mistaken for tic douloureux of the third division of the trigeminal nerve. The differential points are discussed under glossopharyngeal neuralgia.

Neuritis of the trigeminal nerve differs from tic douloureux in that the pain is fairly steady, lasting for hours or days.

Sensory stimuli may or may not aggravate the pain. The cause is usually an infectious or toxic agent produced by disease of the face, jaws, or teeth. Tumors or infections of the gasserian ganglion occasionally are the cause of this neuritic type of pain.

One-third as common as trigeminal neuralgia is the chronic pain called atypical facial neuralgia. In this category may be included sphenopalatine neuralgia. Intracranial section of the fifth nerve does not relieve this type of pain.

### MINOR SURGICAL PROCEDURES

The pain of trigeminal neuralgia may be effectively relieved temporarily by interruption of the divisions or branches of the fifth nerve, by avulsion, surgical section, alcoholic injection, or electrocoagulation. These procedures produce anesthesia of the skin or mucous membrane supplied by the nerve, thereby relieving the pain. However, the nerve always regenerates, the area of anesthesia fades, and the pain returns. One of these methods is warranted if the patient understands that the object is to provide temporary respite. If the diagnosis of tic douloureux is in doubt, such a procedure on a peripheral nerve is amply justified. If avulsion or alcoholic injection produces anesthesia and the pain persists in the anesthetic area, the patient does not have trigeminal neuralgia, and intracranial section of the fifth nerve is contraindicated. A poor excuse for performing this procedure is that it will teach the patient how anesthesia of the face feels. It is highly improbable that any patient suffering from severe trigeminal neuralgia ever refused the intracranial operation because he did not like the anesthesia which a nerve injection temporarily produced.

**Destruction of Supra-orbital Nerve.** Occasionally, the lightning-like pains of trigeminal neuralgia are limited to the distribution of the supra-orbital nerve. In such cases relief may be effected by

destruction of the nerve, either with injections of alcohol or by section. The procedure for destroying the nerve by injections of alcohol is carried out as follows: The supra-orbital notch is palpated, and then a hypodermic needle is inserted into the supra-orbital foramen or groove, as the case may be. A few drops of procaine hydrochloride are injected with a 2-cc. syringe, one drop at a time, until half the
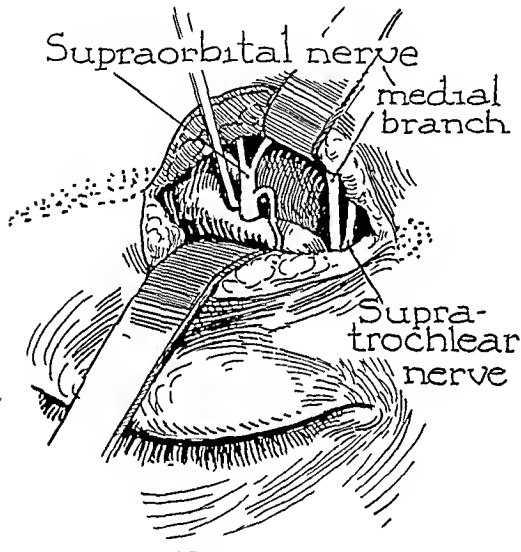


Fig. 134. Incision in eyebrow to expose supra-orbital nerve as it emerges from supra-orbital foramen. Medial branches of supra-orbital nerve and supratrochlear nerve are also cutaneous nerves and should be severed.

forehead has become anesthetic. This should be followed by not more than 0.5 cc. of 95 per cent alcohol. The point of the needle should be moved several times so that as many fibers of the nerve as possible come in contact with the alcohol. The procedure is naturally painful and edema of the eyelid develops. There are no permanent ill effects from such an injection. Its disadvantages are that the anesthesia and the relief of pain are often incomplete or short-lived, due chiefly to the fact that the

supra-orbital nerve has numerous branches, some of which may not be reached by the alcohol.

Section or avulsion of the nerve offers a more effective method of destroying it (Fig. 134). The technic is as follows: A horizontal incision is made exactly at the upper border of the shaved eyebrow after the region has been infiltrated with 1 per cent procaine hydrochloride. If the incision is not made at the upper border of the eyebrow but is made through it, a visible scar will result. Hemostats are applied to the subcutaneous vessels and the wound is spread with retractors. The dissection should be carried to the notch or foramen where the supra-orbital nerve and vessels can be picked up with a hook. The nerve should be carefully dissected back into the foramen or orbit so that all of the branches are found. A section of the nerve 2 cm. in length should be removed. The medial branch of the supra-orbital nerve and the supratrochlear nerve should be severed also. The deeper tissues and the skin should be approximated with a few sutures. This procedure produces anesthesia of part of the forehead and relief of pain which may last for as long as two years.

**Destruction of Infra-orbital Nerve.** If the pain is limited to the cheek and upper lip, alcoholic injection or surgical section of the infra-orbital nerve will produce anesthesia of this region and bring about temporary freedom from attacks. If the patient also has pain in the palate or upper gum, relief must not be expected, for the infra-orbital nerve does not supply the mucous membrane of those structures.

In carrying out the alcoholic injection the infra-orbital foramen is first palpated. Because the canal points medially and downward, the needle should be inserted into the skin about 1 cm. below the foramen. A long hypodermic needle should be used. After the point is definitely felt to enter the foramen, the needle can be in-

serted for about 1 cm. (Fig. 135). Aspiration with the syringe should then be attempted; if air is obtained it indicates that the point of the needle is in the antrum and that alcoholic injection is unsafe. If air is not obtained a few drops of procaine hydrochloride should be injected,

method, there are occasional cases in which satisfactory anesthesia is not obtained. Under such circumstances surgical section of the infra-orbital nerve is performed. After the skin and infra-orbital nerve have been infiltrated with a solution of 1 per cent procaine hydrochloride, a transverse
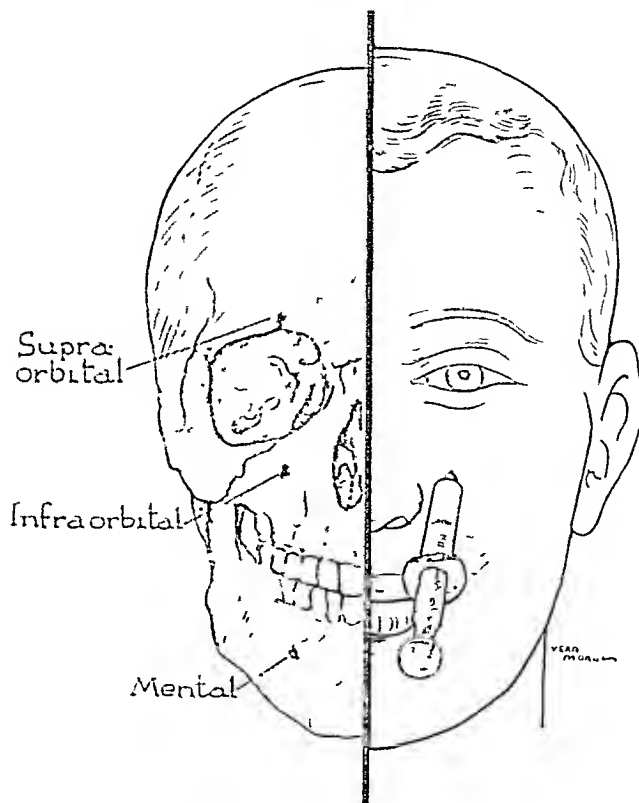


Fig. 135. Method of injecting alcohol into infra-orbital foramen with 2-cm. needle and small syringe.

followed by 1 cc. of 95 per cent alcohol, one drop at a time. The point of the needle should be moved several times to insure destruction of all fibers. Such a procedure results in anesthesia of half the upper lip, the lower eyelid, part of the cheek, and the side of the nose. The anesthesia and relief of pain may last for many months; rarely does it last more than a year.

Although alcoholic injection of the infra-orbital nerve is certainly the preferred

incision 3 cm. in length is made directly over the infra-orbital foramen. The nerve is avulsed from the foramen or a piece of it may be removed. Although the majority of patients with infra-orbital neuralgia are past the age of 50 and not dismayed by a small scar on the face, younger patients may prefer the following approach through the mouth: After anesthesia has been obtained by injecting the infra-orbital nerve with procaine hydrochloride, the upper lip

is retracted. An incision 3 cm. in length is made in the mucous membrane just above the alveolar border (Fig. 136), and carried to the bone. Upon elevation of the periosteum the foramen and nerve are immediately encountered. The latter is grasped with a hemostat and avulsed. The incision is closed with fine catgut sutures, and a pressure bandage is applied to the cheek.

The mental nerve, a branch of the third division which becomes superficial at the
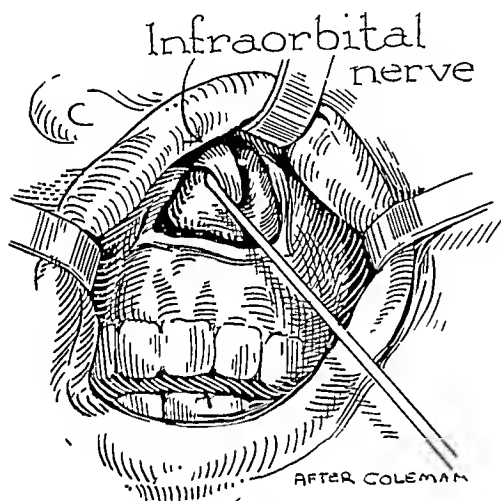


FIG. 136. Exposure of infra-orbital nerve through mouth. Upper lip is retracted to permit incision of mucous membrane just above alveolar border. (After Coleman.)

mental foramen in the mandible, is another easily accessible nerve for injection or surgical section (Fig. 135). However, this nerve supplies only a small area of skin near the point of the jaw and indication for its injection is rarely encountered.

Alcoholic Injection of Maxillary Division. More useful, but more difficult to perform, are alcoholic injections of the second and third divisions of the fifth nerve as they emerge from the base of the skull through the foramina rotundum and ovale (Fig. 137). When alcohol is successfully injected into the maxillary division there is anesthesia of the cheek, side of the nose, upper lip, upper gum, and palate. The procedure is as follows:

Until thoroughly familiar with the procedure, it is well to have an assistant hold a skull near the patient's head to assist the operator in maintaining three-dimensional orientation. Following a superficial injection of procaine hydrochloride or other local anesthetic, a 22-gauge spinal-puncture needle is inserted through the skin of the cheek just below the zygoma. The point of the needle is directed medially and cephalad; it should strike the base of the skull, near the region of the foramen rotundum, at the depth of about 5 cm. If the point of the needle pierces the nerve, the patient cries out with pain which is felt in the upper lip. A few drops of procaine hydrochloride will produce anesthesia in the distribution of the entire division; this should be followed by the slow injection of 1 cc. of 50 per cent alcohol. Alcohol must not be injected if anesthesia is not produced by the procaine hydrochloride. If, on the other hand, the nerve is not pierced by the needle on the first attempt, the operator is forced to probe in that neighborhood until he does strike the nerve. The chief danger of this method lies in the possibility of injecting alcohol into or around the optic or the oculomotor nerves.

Alcoholic Injection of Mandibular Division. The mandibular nerve at the foramen ovale is less difficult to hit than the maxillary division. The spinal-puncture needle is inserted into the cheek just below the zygomatic notch (Fig. 137). The point of the needle is directed medially and slightly posteriorly. The base of the skull in the region of the foramen ovale is encountered at a depth of about 4.5 cm. When the nerve is pierced by the point of the needle, pain is experienced in the lower jaw, lower lip, or tongue. A few drops of procaine hydrochloride injected at this point will result in anesthesia of the lower lip; this should be

followed by the slow injection of 1 cc. of 50 per cent alcohol. Here the chief hazards to be borne in mind are the possibility of puncturing the middle meningeal artery and the risk of injecting alcohol into the eustachian tube.

pain always returns; (4) the injection is often a complete failure even in expert hands; (5) subsequent alcoholic injections are less satisfactory because scar tissue prevents diffusion of the alcohol throughout the nerve trunk.
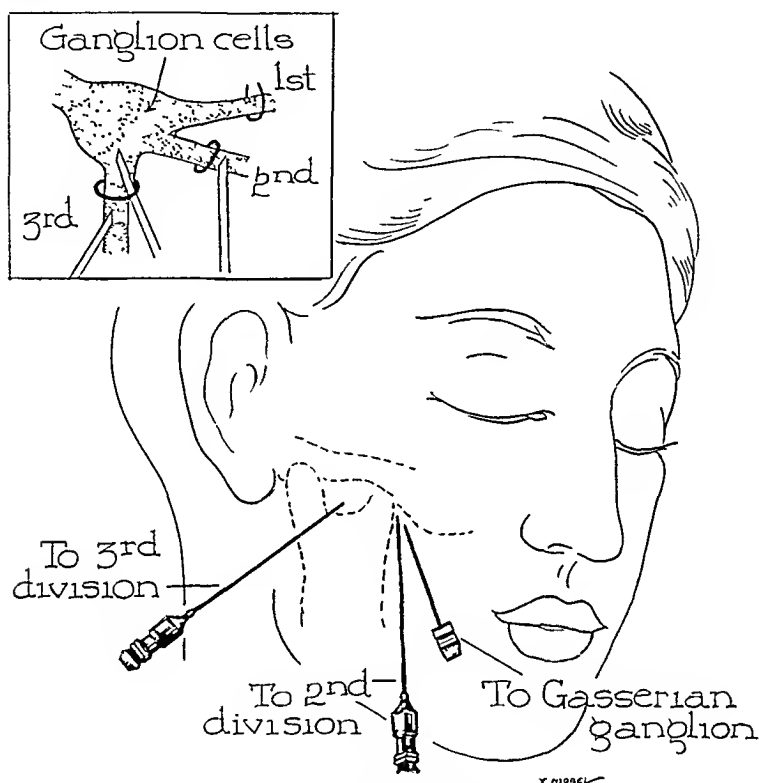


FIG. 137. Diagram showing approximate positions of needles for alcoholic injections of third division, second division, and ganglion of fifth nerve.

**Disadvantages of Alcoholic Injection of the Three Divisions.** Alcoholic injection of the ophthalmic division of the fifth nerve is too dangerous to be attempted. There are five chief objections to injection of any of the divisions of the fifth nerve: (1) It is extremely painful, since it must be done with local anesthesia; (2) adjacent structures are always damaged by the alcohol; (3) this procedure never cures the disease —it gives relief for weeks or months and occasionally for one or two years, but the

**Alcoholic Injection of Gasserian Ganglion.** Of the nonoperative procedures for the relief of trigeminal neuralgia, alcoholic injection of the gasserian ganglion is the most effective.* Unfortunately, it is also the most difficult and most dangerous. This injection may be carried out under general

* Kirschner's method of destroying the ganglion by electrocoagulation apparently has not been given a trial in this country. For a report on this method, see Besselaar, H. J., and R. S. Verster: Electrocoagulation of the gasserian ganglion with Kirschner's apparatus, South African Med. Jour., **16**:209

sion is made and metycaine, 1 per cent, or procaine hydrochloride is injected along this line at three points so that sutures or towel clips for holding three towels in place may be inserted without causing pain. The line of incision is infiltrated throughout, the point of the needle being inserted to the skull.

A straight incision 8 cm. long is made 2 cm. in front of the ear, extending from a

bone is exposed by use of a self-retaining retractor of appropriate size and shape. A trephine opening is made in the squama of the temporal bone and enlarged with a rongeur to the size of a 50-cent piece. The lower border of the opening is at the zygomatic ridge. If air cells are opened they should be closed with bone wax. The dura is gently freed from the inner surface of the skull for a distance of about 1 cm.
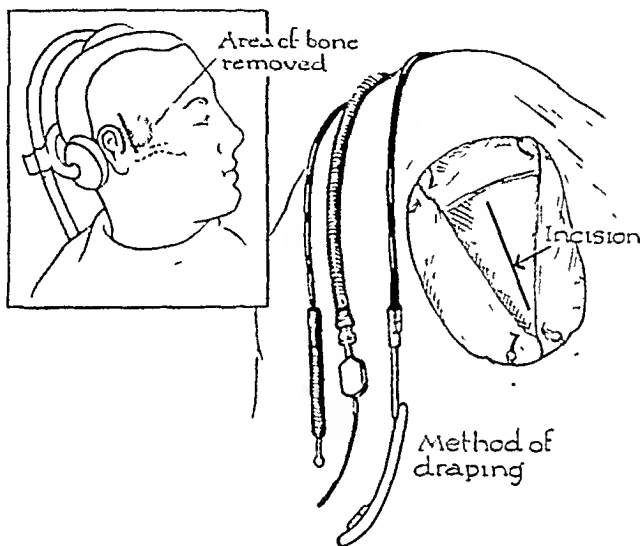


Fig. 138. Temporal approach for section of trigeminal nerve. Patient is in sitting position. Instruments shown: electric coagulator, metal sucker, electrically lighted retractor.

little above the ear to the zygomatic process of the temporal bone (Fig. 138). The incision should not be carried below the zygomatic arch as branches of the facial nerve may be damaged. The incision is carried through the skin and subcutaneous tissues. The temporal artery is usually cut one or more times by this incision, and the spurting ends must be ligated or coagulated. Hemostats, placed on the subcutaneous tissues, are fastened to the drapes with rubber bands and towel clips. The incision is then carried through the temporal muscle and periosteum. The temporal

around the periphery of the opening in the skull. The room should be made as dark as possible so that a lighted retractor can be more effectively used for the intracranial part of the operation. The dura covering the temporal lobe is gradually lifted from the floor of the skull by means of the lighted retractor and gentle dissection with the tip of the sucker. If the dura is very adherent sharp dissection with a ganglion knife is necessary.

The operator proceeds in a medial and slightly anterior direction until the middle meningeal artery is encountered at its point
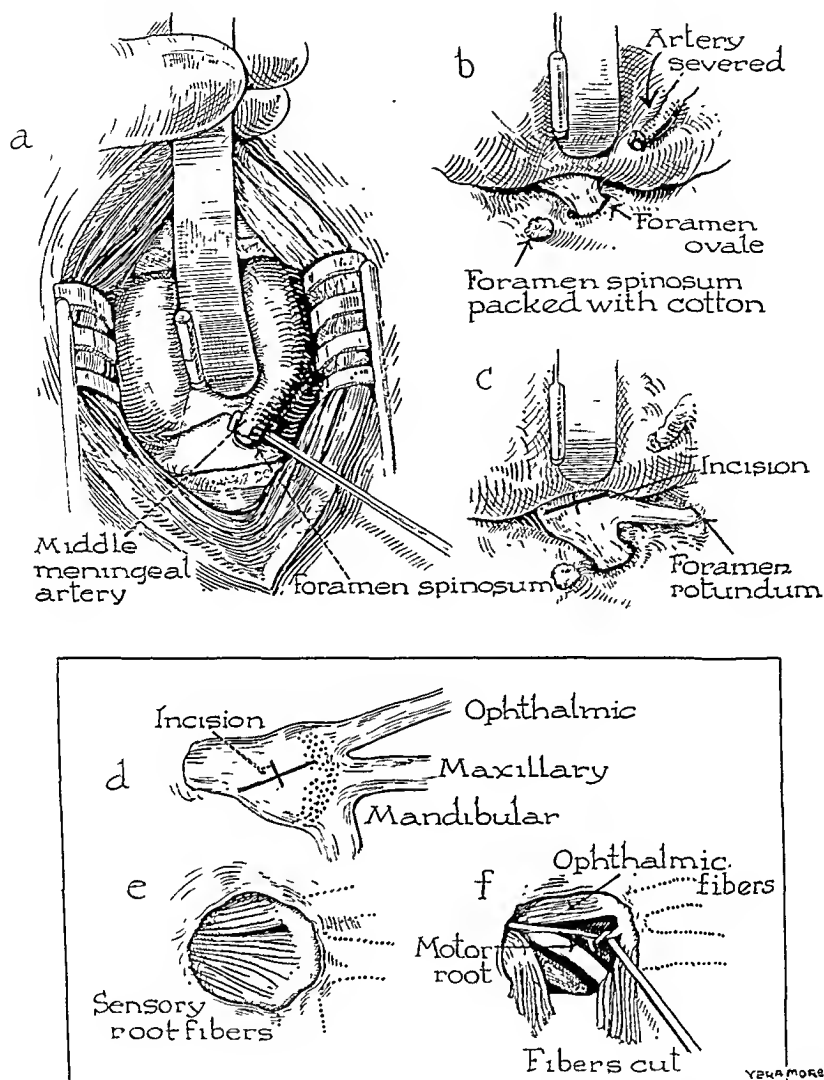
FIG. 139. Details of intracranial section of fifth nerve by extradural temporal route: (a) Middle meningeal artery. (b) Middle meningeal artery is coagulated and severed after packing cotton into foramen spinosum. (c) Dura has been retracted to expose third and second divisions of the nerve. (d) Cross-shaped incision is made in sheath of ganglion. (e) Sensory filaments are exposed just proximal to ganglion cells. (f) Sensory filaments are cut or avulsed one at a time. Large motor root lies under sensory fibers.

of emergence from the foramen spinosum (Fig. 139). This artery is isolated by blunt dissection and coagulated. Because manipulation of the artery is painful, a pledget of cotton moistened with a local anesthetic may be laid against the artery for a minute to anesthetize the nerve endings. A small wisp of cotton is then pressed into

the foramen spinosum with the type of dental instrument used for filling teeth. As soon as the artery has thus been doubly obliterated, it may be cut with knife or scissors and given no further attention.

Just anterior and medial to the foramen spinosum, the third division of the fifth nerve is encountered at the foramen ovale. It can be injected with a few drops of metycaine or procaine hydrochloride. The most important part of the operation lies in properly finding the line of cleavage between the sheath of this nerve and the overlying dura of the brain. With blunt dissection the dura is separated from the third division close to the foramen ovale. It will be noted that the dura seems especially adherent to the posterior border of the gasserian ganglion near the exit of the third division and at a second point 10 to 15 mm. posteriorly on the floor of the middle fossa. This is the greater superficial petrosal nerve emerging from the geniculate ganglion through a small opening in the bone and passing along the floor to disappear beneath the lower posterior edge of the gasserian ganglion. It is quite adherent to the temporal dura and should be separated from it by sharp dissection, using a right-angled knife. The superficial petrosal nerve should always be preserved to prevent a dry nasal mucous membrane. The dura is then further elevated from the third division and part of the second, exposing the gasserian ganglion and the dura propria over the sensory root. The first division of the nerve should not be exposed. During the dissection the field should be kept dry by continuous use of the sucker. Bleeding veins may be controlled by electrocoagulation or compression with a cotton pledget.

The dura enclosing the sensory root is incised just posterior to the ganglion. This incision is horizontal and in line with the second division of the nerve (Fig. 139 D). An additional cut in a transverse direction may be made. The sensory rootlets can be

seen floating in the subarachnoid fluid, which escapes in considerable quantity when the arachnoid is opened. The most laterally placed of these rootlets go to form the mandibular division. These may be cut with a right-angled knife or picked up with a hook and cut with scissors. In a similar manner all the rootlets are severed, one or two at a time, unless the ophthalmic fibers are to be preserved. This is highly desirable and should always be attempted if this division has not been affected. Generally the ophthalmic fibers in the sensory root are slightly separated from the adjacent maxillary fibers at the ganglion. The former swing upward just before entering the ganglion while the second division fibers pass directly forward. This leaves a small triangular space between the rootlets of the two divisions. Preservation of these uppermost fibers insures sensation in the cornea, upper eyelid, and forehead. On numerous occasions the authors have successfully divided only the second- or third-division fibers of the sensory root when pain had been felt only in the area supplied by either of these divisions. Since there is no anatomic separation between the lowermost fiber going to the second division and the uppermost fiber of the third, identification of the respective rootlets can be made only by gently pinching the fiber with bayonet forceps and asking the patient to tell where pain is produced. Some patients are too sleepy from the hyoscine and morphine to cooperate satisfactorily.

Before the section of the sensory rootlets it is important to identify and carefully preserve the motor root which lies under the sensory fibers. It runs in a slightly different direction—i.e., diagonally downward and forward—and is somewhat larger than the sensory fibers (Fig. 139 F).

Numerous difficulties may be encountered during this operation. If, as frequently happens, a branch of the middle meningeal artery tears and bleeds pro-

fusely while the skull opening is being enlarged, the artery should be immediately exposed and coagulated. When the dura is elevated from the floor of the skull and from the sheath of the ganglion, venous bleeding from small dural sinuses occurs. This is controlled by coagulation of ·the bleeding points or by packing a pledget of cotton (to which a suture is fastened) against the bleeding point. If ·such vessels continue to bleed after removal of the cotton, a piece of temporal muscle should be cut off, crushed with a hemostat, and placed on the bleeding point. The application of the crushed muscle causes immediate coagulation. Fibrin foam saturated with thrombin can be used in place of muscle. Almost constant suction is required to keep the floor of the skull clear of the cerebrospinal fluid which escapes from the opening in the gasserian sheath. Also, throughout the entire procedure, the temporal lobe must be elevated with a lighted retractor held by either the operator or an assistant.

When the lighted retractor is removed and the temporal horn of the lateral ventricle again fills, the temporal lobe gradually comes back into position on the floor of the skull. The dura can be promptly expanded by injecting 10 to 20 cc. of normal saline subdurally with syringe and needle. The temporal muscle, subcutaneous tissues, and skin are tightly closed with interrupted sutures of silk or cotton. The operation requires from 20 minutes to two hours, depending on the difficulties encountered and the personal characteristics of the surgeon. A small gauze dressing, slightly longer and wider than the incision, is fastened in place with adhesive tape.

### INTRADURAL TEMPORAL APPROACH FOR SECTION OF TRIGEMINAL NERVE

The intradural temporal approach for section of the fifth cranial nerve is used routinely in only a few hospitals. After the opening in the temporal bone has been fashioned, a flap of dura is reflected downward. The temporal lobe is then elevated with a lighted retractor. Moist sheets of cotton should be placed between the retractor and the brain so that the latter will not be contused. The gasserian ganglion is located by palpation with a blunt instrument and the overlying dura is opened in a stellate manner. The rest of the operation does not vary from the technic used for the extradural temporal approach except that the dural flap must be closed.

The chief advantage of this operation is that the greater superficial petrosal nerve is not exposed and consequently there is less possibility of facial paralysis. A less important factor is that ligation of the middle meningeal artery is avoided. The possibility of traumatizing the temporal lobe and its vessels is the principal disadvantage of the operation and in the opinion of the authors outweighs the advantages.

### OCCIPITAL APPROACH FOR INTRACRANIAL SECTION OF TRIGEMINAL NERVE

Some surgeons prefer the occipital (cerebellar) approach (Fig. 140) to the fifth nerve. This operation is performed under local or general anesthesia and in either the prone or upright position with the face in the head rest. A vertical scratch indicating the site of the incision is made just posterior to the mastoid process. It extends from slightly above the occipital ridge downward to the level of the mastoid tip. In thick-necked individuals the upper end of the incision may be curved posteriorly for from 3 to 4 cm.

The incision is carried through the skin. subcutaneous tissue, muscle, and periosteum. The periosteum is scraped from the skull and a self-retaining retractor inserted to spread the skin and muscles. An area of bone about 4 cm. in diameter should be exposed. A trephine opening is made and then enlarged with a rongeur. The opening is extended anteriorly to the mastoid. If an

air cell is actually opened it can be closed with a piece of bone wax. With experience and with cautious removal of bone it is possible to carry the opening well laterally without actually opening an air cell. The opening is carried superiorly until the lateral sinus is seen. The completed opening in the skull should be roughly circular and 3 cm. in diameter.
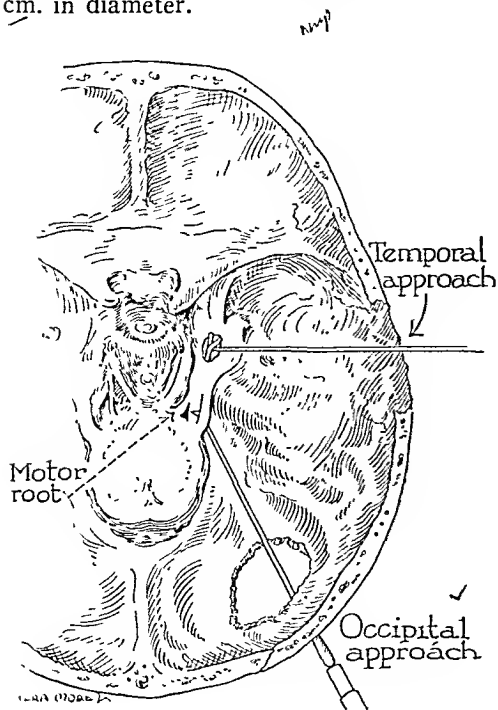


FIG. 140. Diagrammatic representation of temporal approach and occipital approach to trigeminal nerve. Upper instrument has picked up a single sensory fiber. Lower instrument is executing a partial section of the nerve.

The dura is opened with a U-shaped incision, great care being taken not to open the lateral sinus. A lighted retractor is slipped between the dura and the posterior surface of the cerebellar hemisphere and pointed in the direction of the foramen magnum. The arachnoid of the cisterna magna is identified and punctured with a small knife or torn with a sharp hook to permit escape of cerebrospinal fluid and facilitate retraction of the cerebellum. The lighted retractor is reinserted in front of the cerebellar hemisphere, and the cerebellum is gently retracted backward. Strips of moist cotton should be placed between the retractor and the cerebellar hemisphere to prevent damage.

The eighth nerve and the tentorium immediately come into view. The veil of arachnoid which forms the lateral extension of the cisterna pontis is opened by tearing it with a pointed hook. The fifth nerve is less accessible than the eighth, lying about 1.5 cm. more medially and slightly farther forward (Fig. 141). The fluid in the cisterna is removed with a sucker, the tip of which should be protected by a small cotton pledget to prevent the possibility of damaging nerves or blood vessels. In a few cases the nerve remains partially hidden by a small vein extending from the cerebellum to the superior petrosal sinus or by arterial loops. A small vein can be doubly clipped with silver clips or coagulated and then cut with the scissors. The large vein passing from the cerebellum to the superior petrosal sinus should be carefully preserved. Occasionally mere retraction of the cerebellum causes some tearing of a vein and bleeding begins. This venous bleeding may be safely controlled by placing a small cotton pledget against the vein at its entrance to the superior petrosal sinus; a suture 15 cm. in length should be attached to the pledget to prevent its being lost or forgotten. Sometimes the oozing vein may be grasped with a bayonet forceps and coagulated. Because uncontrollable bleeding in this region would frustrate the entire operation, the approach to the nerve must be made with great precision and with constant care to avoid too much traction on the veins entering the sinus.

If the operator has an assistant capable of holding the lighted retractor he may

pick up the fifth nerve with a hook and cut it with scissors. If he prefers to hold the lighted retractor himself he must first isolate the nerve with a hook to make sure that an artery is not hidden behind it. Either a sharp hook or scissors may be used to cut the nerve. Some surgeons prefer to crush or coagulate the nerve before nerve nearest to the eighth cranial nerve, that is, the part of the nerve most easily accessible to the operator, since it is assumed that the fibers which carry pain lie in this part of the nerve. The motor root lies medially and anteriorly to the sensory root. If there is no bleeding the lighted retractor may be slipped out and the protec-
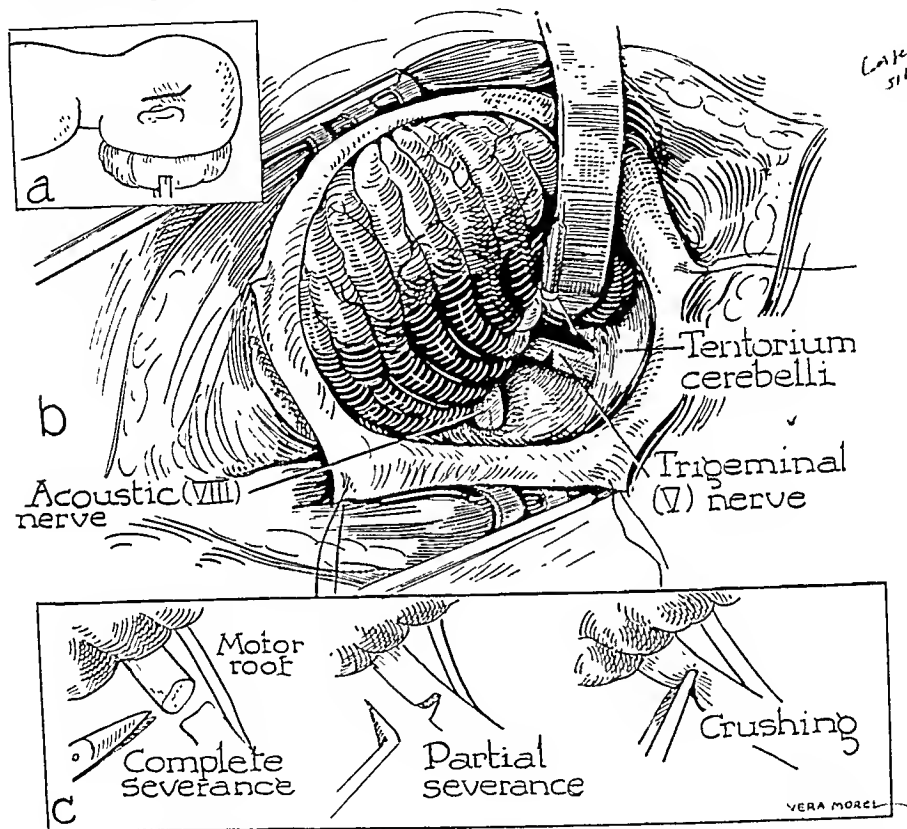


FIG. 141. (a) Occipital approach for section of fifth nerve. (b) Cerebellar hemisphere is retracted medially to expose fifth nerve. Sheets of moist cotton which protect cerebellum are not shown. (c) Methods of cutting nerve.

cutting. If all of the nerve is cut there will be complete and permanent anesthesia of the corresponding side of the face. If only half or two-thirds is cut considerable tactile sensation will be preserved in the face, but the possibility remains that a few pain-carrying fibers may escape, requiring a second operation. When only two-thirds of the nerve is cut it must be that part of the tive sheet of cotton removed from the surface of the cerebellar hemisphere.

The incision in the dura is partially closed with interrupted sutures. A water-tight closure in this region is usually unobtainable unless a muscle graft is used. The wound is closed in layers with interrupted sutures of silk, cotton, catgut, or stainless steel.

## POSTOPERATIVE CARE

Because these patients are usually old, they should not be permitted to lie flat in bed for any length of time, but should be propped up with a back rest and pillows. Fluid and food may be given as rapidly as the patient can tolerate them. The sutures may be removed on the third postoperative day. Headache, from loss of cerebrospinal fluid, is a common complaint. Depending on his wishes the patient may become ambulatory in from four to six days. The average length of stay in the hospital is seven days.

When the ophthalmic fibers of the nerve have been sectioned there is absence of corneal sensation, consequently foreign bodies on and injuries to or infections of the cornea are dangerous; an irritating foreign body may remain undetected for several days. The patient must be careful not to damage the cornea with a towel or the finger, and he should be taught to inspect the eye in the mirror for any redness indicating inflammation from a foreign body.

Each patient should be instructed to go to a physician immediately if an optic complication develops. In the case of severe inflammation or ulceration the eyelids should be sutured together for several months. If the patient desires he may wash the eye once or twice a day with boiled water. Some surgeons equip all these patients with goggles which are worn during the hospital stay. Later they may wear a pair of glasses which has a shield to keep dust and foreign bodies from striking the eye. Others do not feel that it is necessary to observe these precautions. Persistent keratitis at times responds favorably to cervical sympathectomy.

## SEQUELAE OF OPERATION; COMPARISON OF TEMPORAL AND CEREBELLAR APPROACHES

Section or partial section of the sensory root of the fifth nerve by the temporal approach may result in certain major and minor unpleasant sequelae. These include: (1) Temporary herpetic lesions of the face, (2) keratitis and corneal ulceration, (3) facial paralysis, (4) deafness, (5) brain damage, (6) postoperative hemorrhage or infection, (7) paralysis of the muscles of mastication, (8) trophic lesions of the skin and mucous membranes, and (9) paralysis of the sixth cranial nerve.

Regardless of the surgical approach used, herpetic lesions appear on the mucous membrane and skin of the lips or cheek from 24 to 48 hours after operation in a high percentage of cases. These lesions are transient, painless, and of no consequence. Keratitis and corneal ulceration are occasional complications which follow section of the fibers supplying the ophthalmic division. If the ophthalmic fibers are left intact at operation, such complications are rare. Although some advocates of the cerebellar approach maintain that keratitis rarely occurs when this technic is followed, we observe that it occurs just as frequently as when the temporal approach is used. Transient facial paralysis sometimes follows section of the nerve by the temporal approach; often it does not develop until several hours to days after the operation. The mechanism which produces this paralysis probably is as follows: the operator inadvertently pulls on the greater superficial petrosal nerve during the process of separating the dura from the floor of the skull. As this nerve is attached to the seventh nerve at the geniculate ganglion the pull results in traction on the seventh nerve with resulting edema and facial palsy. With the technic herein described for the extradural temporal approach the incidence of temporary facial paralysis is less than 1 per cent.

Although facial paralysis cannot occur in this manner when the cerebellar approach is used the seventh nerve can be damaged directly. Transient deafness and a feeling

of fulness in the ear sometimes follow operation by the temporal approach. Probably this occurs only when the operator inadvertently opens a zygomatic air cell and fails to note that cerebrospinal fluid runs into this opening and thus to the middle ear. The mastoid air cells could likewise permit the entrance of fluid when the cerebellar approach is used, but the operator is much less likely to fail to notice such an opening. The eighth nerve is always in full view during the cerebellar operation and may be damaged along with the seventh nerve.

Superficial injury to the temporal lobe when the temporal approach is used can occur if the dura protecting the brain is torn. However such an injury is of little consequence since the under surface of the temporal lobe is not clinically important. Damage to the brain incident to the cerebellar approach is much more liable to occur as the operation is performed intradurally. Postoperative hemorrhage or infection are obviously serious complications in the case of the cerebellar approach. Permanent paralysis of the muscles of mastication will result if the motor root of the fifth nerve is divided. However this root is easily identified in the temporal approach, and there really is no excuse for injuring it. With the cerebellar approach there is little danger of cutting the motor division as this is quite separate from the sensory root and about 3 mm. medial to it.

Thus it may be seen that there are certain advantages and disadvantages of the two approaches. In favor of the temporal route, one may confidently say there is little likelihood of death or serious complications during the performance of the operation. The mortality rate in most hospitals is less than 1 per cent. On the other hand, if bleeding gets beyond control when the cerebellar approach is used, it is possible to damage several cranial nerves. The cerebellar approach should be used if there

are signs or symptoms suggesting a causative lesion in the cerebellopontile angle.

## POSTOPERATIVE PARESTHESIA

By far the most common and important of the complications resulting from section of the fifth nerve for trigeminal neuralgia is the occurrence of unpleasant sensations in the anesthetic part of the face. Ten per cent of patients return to the surgeon complaining of sensations of crawling, itching, numbness, or gnawing in the region where they originally had the pains of trigeminal neuralgia. This condition may correspond in a way to the sensations sometimes felt after amputation of an extremity. It is not known why some amputation stumps are chronically painful and others painless; likewise it is not known why some patients with trigeminal neuralgia have postoperative paresthesias and others do not. In severe cases, section of the sympathetic chain on the corresponding side of the neck has been tried, but without relief. This complication is very annoying to some patients.

## TRIGEMINAL TRACTOTOMY

Trigeminal tic douloureux and other fifth-nerve pains can also be stopped by severing the spinal tract of the fifth nerve in the medulla oblongata as suggested by Sjoqvist. The fifth cranial nerve, after entering the pons, undergoes an anatomic dissociation. The fibers which convey tactile sensation turn superiorly to enter the main sensory nucleus of the trigeminal nerve. The fibers which mediate pain and temperature sensation, on the other hand, turn inferiorly and descend into the upper portion of the cervical spinal cord. The fibers which descend are known as the spinal tract of the fifth nerve and are closely approximated to the spinal nucleus of the fifth nerve. At the lower portion of the

medulla this descending tract and its nucleus are near the surface and form a distinct elevation called the tuberculum cinereum.

The technic of trigeminal tractotomy is as follows: After the posterior half of the head has been shaved the patient is placed in the prone position on the operating table. However some surgeons prefer the sitting position (Fig. 142). Intratracheal ether or a local anesthetic supplemented with avertin or with morphine and scopo-



FIG. 142. Many surgeons prefer to have patient in sitting position for operations on cerebellum and cervical spinal cord. This drawing shows a makeshift device. Special operating tables for this purpose are available.

lamine may be used. A suboccipital craniectomy is performed through a midline incision, and the posterior margin of the foramen magnum is removed. It is not always necessary to remove the arch of the atlas but the exposure is greatly improved if this is done. The dura is opened in a stellate manner to expose the inferior portion of one cerebellar hemisphere, the medulla,

and the upper part of the spinal cord. The cerebellar tonsil should be protected with a sheet of moist cotton and retracted to expose the inferior portion of the fourth ventricle. The chief landmark in this operation is the obex (Fig. 143). The incision in the medulla is made 4 or 5 mm. (or more, if blood vessels interfere) inferior to the obex as suggested by Grant and Weinberger. The descending tract of the trigeminal nerve and its nucleus are superficial at this level and form a slight prominence on the posterolateral aspect of the medulla known as the tuberculum cinereum. The tuberculum cinereum is transected with a knife blade to a depth of 3 or 4 mm.; the length of the incision on the surface is approximately 5 mm. The external arcuate fibers, which are also cut, and the few dorsal spinocerebellar fibers, which may be cut, produce relatively unimportant and transient symptoms. If the patient is not under general anesthesia special care must be taken in severing the tract, as the procedure induces pain which might cause the patient to move.

In theory this operation has several advantages over the operations which involve severance of the fifth cranial nerve. For example, tactile sensation is retained in the face. Numbness and the related difficulty of finding food on the involved side of the mouth are avoided. Keratitis and corneal ulcerations are unlikely to occur. Paresthesias in the distribution of the fifth nerve do occur after this procedure, but a recent investigation of this point by Grant indicates that such paresthesias are rare. In addition, there is no possibility of injuring the motor root of the fifth nerve during tractotomy. The operation is unlikely to replace the other methods described in this chapter, because it has more inherent dangers. One definite indication for intramedullary tractotomy would be a "one-eyed" patient with tic douloureux involving the ophthalmic division of the good eye.

SECTION OF TRIGEMINAL NERVE FOR
CONDITIONS OTHER THAN
TIC DOULOUREUX

Herpes zoster ophthalmicus in those past 60 years of age is frequently followed by pain in the forehead and eye which may persist for the remainder of the patient's life. This affection should not be mistaken for trigeminal neuralgia. The whitish scars which directly involve the gasserian ganglion, its root, or its three divisions. Relief of the pain is usually obtained by removing the cause. However, this is not always possible, as in chordoma of the base of the skull and carcinoma originating in the nasopharynx. In such cases intracranial section of the fifth nerve or trigeminal tractotomy is a worthwhile procedure.
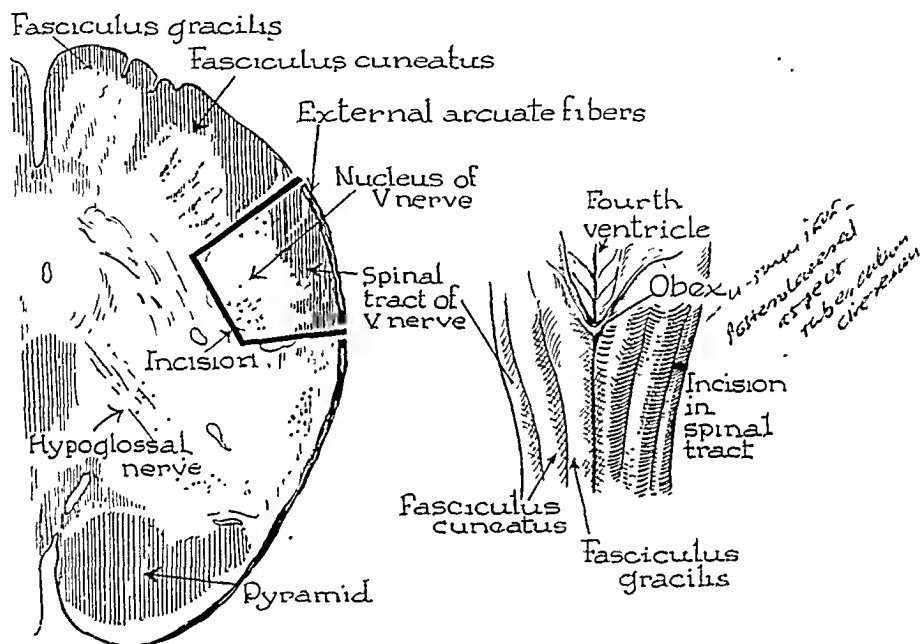


FIG. 143. Right-hand drawing shows portion of brain that is seen at operation. Figure at left illustrates depth and length of incision. Unfortunately, landmarks on medulla are not so distinct as those in drawing.

and the fairly constant nature of the pain readily make the diagnosis. Fifth-nerve section in severe cases would appear to be a logical procedure, but it unfortunately fails to give relief. The pathologic condition causing postherpetic pain is not in the nerve or gasserian ganglion or even in the descending spinal tract. It is probably in the thalamus.

Among the other lesions causing severe and persistent pain in half the face are tumors, aneurysms, and inflammatory lesions

Carcinoma of the face, mouth, tongue, and nasal sinuses may result in severe pain entirely in the distribution of the trigeminal nerve, but usually the pain extends into the sensory domains of other nerves, especially the ninth and upper cervicals. In such cases fifth-nerve section should be combined with section of one or more of the other nerves mentioned.

**Combined Section of Fifth and Ninth Cranial Nerves.** This operation is simply a combination of the fifth-nerve section by

the cerebellar approach already described and section of the ninth nerve described elsewhere in this chapter. It is important to sever the fifth nerve first, since it is the least accessible and requires a greater exposure. Section of the ninth nerve causes an immediate temporary rise in blood pressure which is without clinical significance.

## TRIGEMINAL TRACTOTOMY COMBINED WITH NINTH-NERVE SECTION FOR PAINFUL CARCINOMA

A procedure alternative to the one just described is trigeminal tractotomy combined with section of the ninth nerve. Tractotomy is performed as previously described (Fig. 143) except that the skin incision is extended and considerable bone is removed laterally so as to make the ninth nerve accessible (Fig. 144 A). After the incision in the medulla has been completed the cerebellum on the side of the pain is retracted medially to expose the ninth, tenth, and eleventh nerves, as shown in Fig. 152. The ninth nerve is identified and severed as described under the subject of glossopharyngeal neuralgia.

## TRIGEMINAL TRACTOTOMY COMBINED WITH CERVICAL RHIZOTOMY AND NINTH-NERVE SECTION FOR PAINFUL CARCINOMA

In many cases of carcinoma of the jaw and mouth the pain is in the domain of the upper cervical nerves as well as the trigeminal and glossopharyngeal. It will be noted in Fig. 133 that the superficial cervical plexus supplies the skin overlying the lower half of the mandible. In such cases the cervical plexus must be sectioned in the neck or the sensory roots of the upper three cervical nerves must be sectioned intraspinally.

If the midline skin incision used for trigeminal tractotomy is carried inferiorly about 5 cm., the second and third cervical spines and laminas can also be removed; this permits access to the posterior roots of the upper three or four cervical nerves.

The first cervical nerve does not always have a sensory root. After completion of the trigeminal tractotomy these roots may
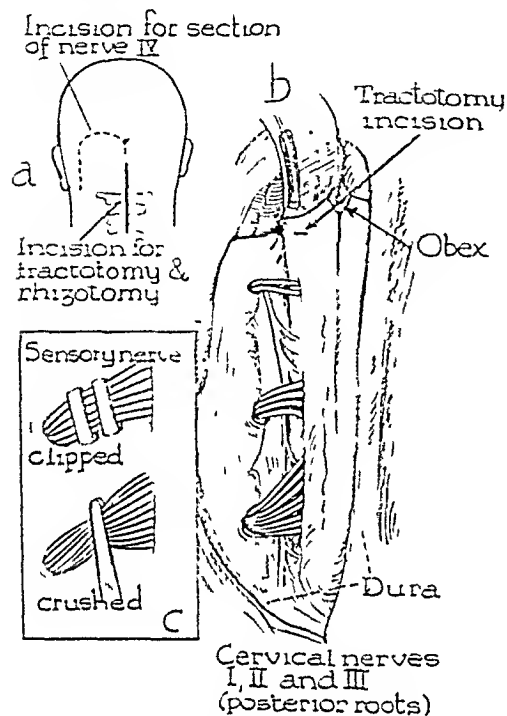


FIG. 144. Combined trigeminal tractotomy, cervical rhizotomy, and glossopharyngeal section for chronic pain in domain of trigeminal, glossopharyngeal, and cervical nerves. (a) Both trigeminal tractotomy and upper cervical rhizotomy can be performed through a midline incision. If section of glossopharyngeal nerve is also required, skin incision can be extended as shown by dotted line. (b) Exposure for combined trigeminal tractotomy and rhizotomy of sensory roots of upper cervical nerves. Posterior margin of foramen magnum has been removed. Bilateral laminectomy is more suitable than hemilaminectomy when rhizotomy is combined with trigeminal tractotomy. (c) Sensory rootlets should be crushed, clipped, or coagulated before sectioning because of the small vessels which run with them.

be severed by one of several methods (Fig. 144). Two silver clips may be placed on each rootlet and the section made between the clips. The rootlets may also be crushed with a hemostat to cause thrombosis of accompanying vessels before cutting with scissors Coagulation of the rootlet with the electrosurgical current and then section with the scissors is effective but painful unless cotton moistened with a local anesthetic is first held in contact with the nerve. When the tractotomy and rhizotomy have been completed the ninth nerve can be sectioned by extending the incision as shown in Fig. 144 A.

### FIFTH- AND NINTH-NERVE SECTION COMBINED WITH EXCISION OF SUPERFICIAL CERVICAL PLEXUS

As already pointed out intracranial section of the fifth and ninth nerve for carcinoma of the jaw and neck does not relieve all of the pain in some cases because of involvement by the tumor of the endings of the sensory fibers of the upper spinal nerves. Frequently a second operation on the cervical plexus is required. This is best done one week after the intracranial procedure.

With the patient in the supine position and with the face turned away from the side to be operated upon, an incision is made along the posterior border of the sternocleidomastoid muscle from just below the tip of the mastoid process to a point 5 cm. above the clavicle (Fig. 145). The smaller occipital nerve is identified as it curves around and ascends along the posterior border of the sternocleidomastoideus. The great auricular nerve winds around the posterior border of the muscle a little lower. The cutaneous cervical nerve turns around the posterior border of the muscle approximately at its middle and passes forward. These nerves are picked up one at a time and dissected somewhat

deeper into the neck. A section of each, at least 2 cm. long, is removed. The great auricular nerve and the cutaneous cervical will be found to join if they are followed sufficiently deep into the neck. The descending branches of the cervical plexus
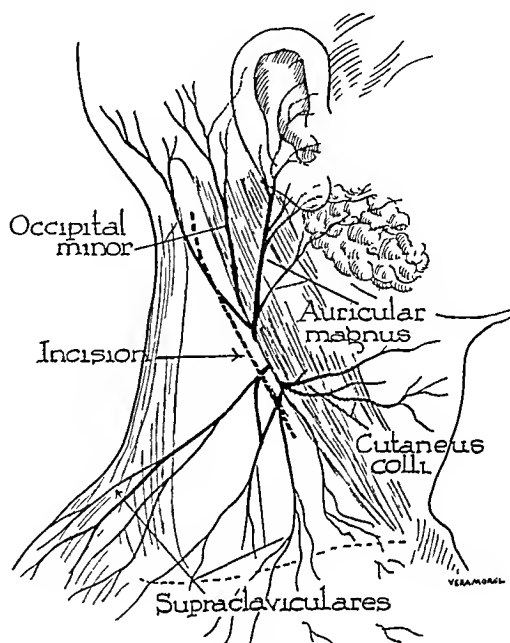


FIG. 145. In cases of chronic pain in region of ear and lower jaw it is necessary to sever ascending and transverse branches of superficial cervical plexus. Incision is made along posterior border of sternomastoid muscle.

are recognized because of their course toward the clavicle and need not be sectioned. The subcutaneous tissues and skin are closed with silk or cotton.

### MESENCEPHALIC TRACTOTOMY FOR RELIEF OF PAIN

A discussion of the surgical methods of relieving pain in the head and neck would not be complete without mention of mesencephalic tractotomy. This is an operation designed to relieve intractable pain occurring on one side of the head and body. It is not a logical procedure for pain in the

lower half of the body since chordotomy is a satisfactory and simpler procedure However, chordotomy at the second cervical segment for the relief of pain in the nerve section, with or without high cervical rhizotomy or neurectomy of the superficial cervical plexus, is fairly satisfactory for the relief of pain in the face and neck, mes-
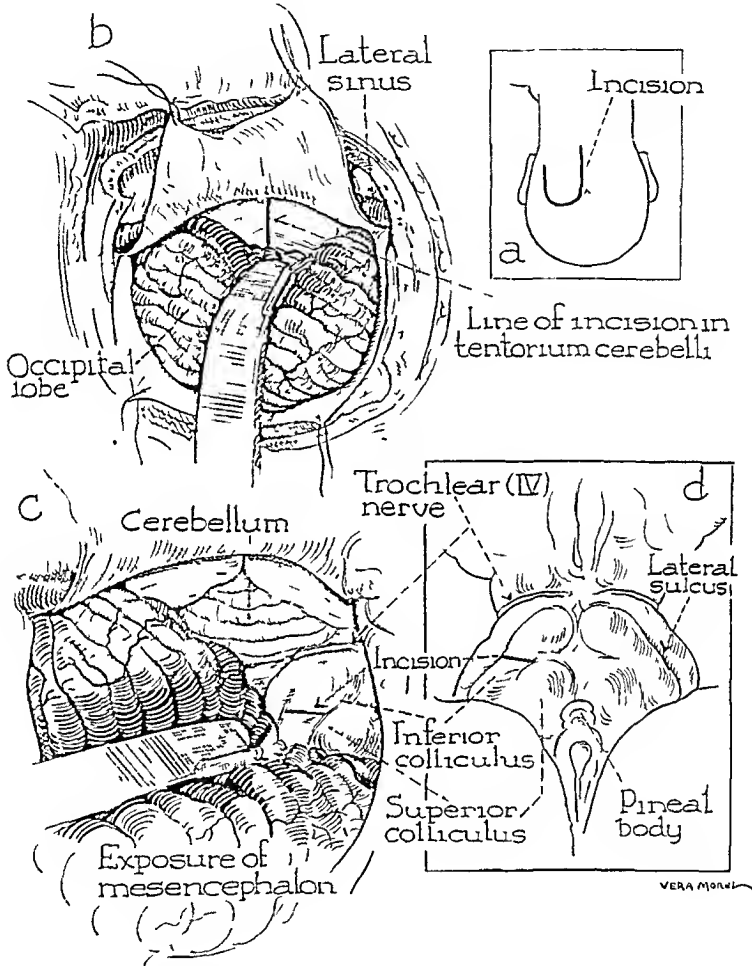


FIG. 146. Mesencephalic tractotomy. (b) Cotton which protects occipital lobe is not shown in this drawing. Tentorium is incised from lateral sinus to incisura, thus exposing cerebellum (c and d). Important landmarks: trochlear nerve, lateral sulcus, superior colliculus Incision across brachium of inferior colliculus extends from lateral sulcus to base of superior colliculus.

chest, arm, or shoulder is not always effective. Cervical rhizotomy likewise is not entirely satisfactory for pain in the arm since extensive anesthesia of the extremity results Whereas combined fifth- and ninth- encephalic tractotomy may prove to be a simpler and perhaps more effective procedure if the pain is felt not only in the face and neck but also in the shoulder, arm, and chest.

In 1938 Dogliotti suggested interrupting the pain and temperature tracts from half the body by an incision in the superior part of the pons. Walker, in 1942, modified this procedure by sectioning the pain fibers in the mesencephalon.

In this procedure an incision is made deep to the brachium of the inferior colliculus where the spinothalamic and secondary trigeminal tracts lie in apposition. Hemianalgesia and hemithermanesthesia of the opposite half of the head and body result. Only slight temporary weakness of the contralateral leg is noted. Coordination and proprioceptive sensibilities are not impaired.

In theory, mesencephalic tractotomy should be a satisfactory way of curing tic douloureux of the fifth and ninth nerves. It should also relieve any other type of head pain including unilateral migraine. However, to date it has been used principally to control the pain produced by malignant tumors.

The anesthetic of choice for mesencephalic tractotomy is avertin and amylene hydrate supplemented by local infiltration of the scalp with procaine hydrochloride. The incision in the scalp (Fig. 146) is made on the side of the head opposite the location of the pain. The medial limb of the incision should begin 3 cm. below and 1 cm. lateral to the external occipital protuberance and should end just medial to the tip of the mastoid process. Four trephines should be made for the bone flap, the two inferior ones being just below the level of the lateral sinus. The bone between the perforations is cut with a saw, except at the base, which is fractured. The dural flap, exposing the occipital lobe, should have the lateral sinus at its base. Veins entering the lateral sinus must be coagulated and cut. The occipital lobe should be covered with sheets of moist cotton and retracted away from the tentorium. The latter is incised from the lateral sinus to the incisura. Adequate room for study of the mesencephalon is obtained by puncturing the cisterna ambiens and sucking away the fluid which escapes. The arachnoid is then teased from the mesencephalon and cerebellum to expose the fourth cranial nerve, the superior cerebellar artery, and the colliculi. Usually a fine plexus of veins lies over the surface of the mesencephalon, but these vessels can be gently pushed to one side to expose the brachium of the inferior colliculus and the lateral sulcus of the mesencephalon.

The incision is made across the brachium of the inferior colliculus, extending from the lateral sulcus to the base of the superior colliculus at the level of its inferior margin. The incision should be made with a sharp-pointed knife to a depth of 5 mm. so as to sever the underlying spinothalamic and secondary trigeminal tracts. Only slight bleeding results. The retractor and cotton sheeting are removed and the dura is closed with interrupted sutures of cotton or silk. The scalp is closed in two layers with interrupted sutures. The postoperative course may be stormy but only the routine care for craniotomy is required.

Rasmussen and Peyton suggest an incision in the mesencephalon at a slightly inferior level; namely, at the level of the emergence of the fourth nerve. They state that a stab wound 3 mm. deep beginning at the attachment of the fourth nerve and extending ventrally 3 or 4 mm. should be ample to interrupt all the pain fibers. Reports of tractotomy at this level in humans have not been made.

## SEVENTH-NERVE NEURALGIA

An extremely rare condition is paroxysmal neuralgia of the seventh cranial nerve, sometimes called geniculate neuralgia or tic douloureux of the nervus intermedius. Only a few reasonably authentic cases have been reported. For this reason it is

impossible to describe a typical case. The one certain feature is pain in the region of the ear. The pain may be more or less constant or may be paroxysmal as in tic douloureux. There is no associated motor disturbance of the seventh nerve. The sensory portion of the seventh nerve, known as the nervus intermedius (pars intermedia of Wrisberg), contains the taste axons from the anterior two-thirds of the tongue and a few somatic sensory axons from the ear. The sensory ganglion of the nerve is the geniculate ganglion located in the facial canal. If a diagnosis of severe and persistent seventh-nerve neuralgia should be made after careful study, section of the sensory branch of the seventh nerve would be indicated.

The approach to the seventh nerve is exactly the same as that used for section of the fifth nerve by the cerebellar approach previously described. With great care the eighth nerve is gently retracted to expose the nervus intermedius lying on the motor division of the seventh nerve (Fig. 151 D). If the operation is performed under local anesthesia it may be possible to reproduce the patient's pain by touching the nerve. This would be a useful procedure in differentiating seventh-nerve neuralgia from ninth-nerve neuralgia. This single threadlike fiber is picked up with a hook and cut or torn.

Other operations for the relief of seventh-nerve neuralgia such as excision of the geniculate ganglion are theoretically possible, but the risk of paralysis of the face is great.

## GENICULATE HERPES ZOSTER

The neuralgic pain associated with herpetic lesions of the tympanum or concha may persist for months or years. This condition is apparently similar to the chronic pain which may follow herpes zoster ophthalmicus. Since intracranial section of the fifth nerve rarely relieves the latter condition, it seems likely that severance of the nervus intermedius would also fail.

## FACIAL TIC AND FACIAL SPASM

Facial tic and facial spasm are somewhat different conditions. The common *facial tic* is characterized by a clonic contraction of some or all of the muscles on one side of the face. Often there are three or four lightning-like twitches of the muscles followed by a period of inactivity during which the patient's appearance is essentially normal. Only the muscles of expression enervated by the seventh cranial nerve are affected. When the muscles about the eye are affected (blepharospasm), the eye is momentarily closed and the patient gives the impression of having deliberately winked. Often the muscles of the lower part of the face take part with quick retractions of the angle of the mouth. When all of the muscles supplied by the seventh nerve are affected, the platysma as well as the ear muscles twitch.

In *facial spasm* the muscles of the face are in a more or less constant (tonic) state of contraction so that the eye is closed and the corner of the mouth is drawn to one side for days or months at a time. Both facial spasm and facial tic can be bilateral. Bilateral facial spasm is a serious problem because the patient cannot open his eyes.

Rarely can the cause of facial tic be determined. It sometimes follows Bell's palsy or injury to the nerve. Some cases of facial tic and most cases of facial spasm are probably the result of traumatic degenerative or inflammatory changes in the basal ganglia of the brain and are thus related to spasmodic torticollis, chorea, paralysis agitans, and athetosis. Facial tic or spasm may follow epidemic encephalitis.

Patients with facial tic or with persistent facial spasm occasionally present themselves for surgical treatment, since medical therapy is usually unsuccessful. There are several possible surgical procedures.

### ALCOHOLIC INJECTION OF PERIPHERAL BRANCHES OF SEVENTH NERVE

As indicated in Fig. 147, the facial nerve divides immediately before or after emerging from the parotid gland into a fanlike group of branches which are distributed
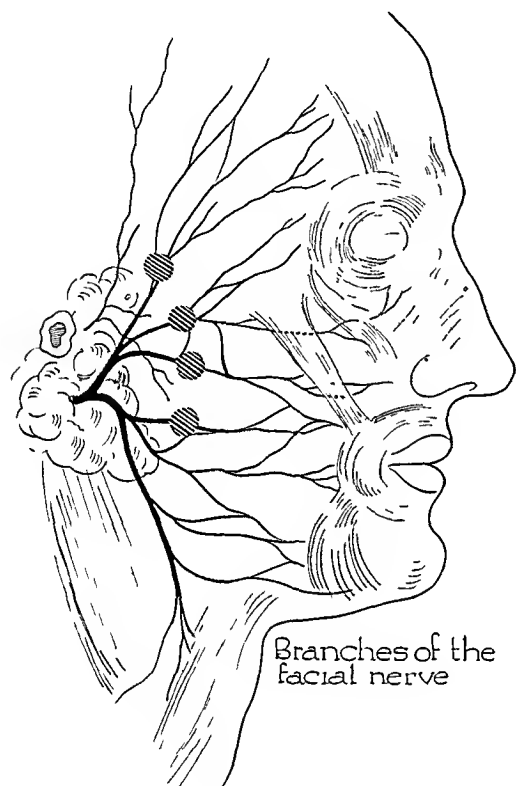


FIG. 147. Facial nerve branches immediately before or after emerging from parotid gland. Circles indicate approximate points where alcohol should be injected to paralyze muscles affected by a tic.

from the frontalis muscle above to the platysma below. A fine hypodermic needle is inserted through the skin and subcutaneous tissues on the side of the face in the general neighborhood of the branch which is to be injected. One cc. of 50 per cent alcohol is slowly injected. Dilution of the alcohol with procaine hydrochloride instead of water will diminish the pain. Since the al-

cohol infiltrates muscle and other tissues as well as the nerve fibers, it is unwise to use alcohol in high concentration or larger amounts because of the danger of necrosis. If, for example, the spasm is limited largely to the orbicularis oculi, the alcohol is injected at one or two points about 2 cm. lateral to the external canthus of the eye. The operator knows that the nerve fibers have been injected when the twitching movements cease. Because of the branching of the seventh-nerve fibers the paralysis obtained is often incomplete. The incompleteness of the paralysis is a desirable feature, but several injections a year may be required. An occasional patient feels that some permanent improvement has resulted from one or more of these injections. The alcoholic injection is undesirable if there is a possibility that the patient might eventually accept a faciospinal accessory anastomosis because the scarring in and around the nerves following the injection might prevent a satisfactory return of function.

### ALCOHOLIC INJECTION OF SEVENTH NERVE AT STYLOMASTOID FORAMEN

Injection of alcohol into the trunk of the facial nerve as it emerges from the skull at the stylomastoid foramen will completely paralyze the muscles of half the face, a condition considered by some patients as more desirable than the facial tic. The ideal result, not always obtainable, is a partial paralysis, i.e., a general weakness of the entire facial nerve which may be obtained by injecting only a few drops of 50 per cent alcohol about the nerve near its exit from the skull. When such a general weakness is obtained, perhaps after only two or three injections, the eye can be voluntarily closed and the corner of the mouth retracted, but not with normal strength. The facial spasms will be completely obliterated or reduced to such an extent as to

be scarcely noticeable. The stylomastoid foramen can be reached with a needle by either a lateral or posterior approach. If the lateral approach is chosen, a 5-cm.-long needle is inserted just below the lobe of the ear and in front of the mastoid process (Fig. 148). It is directed upward and in-
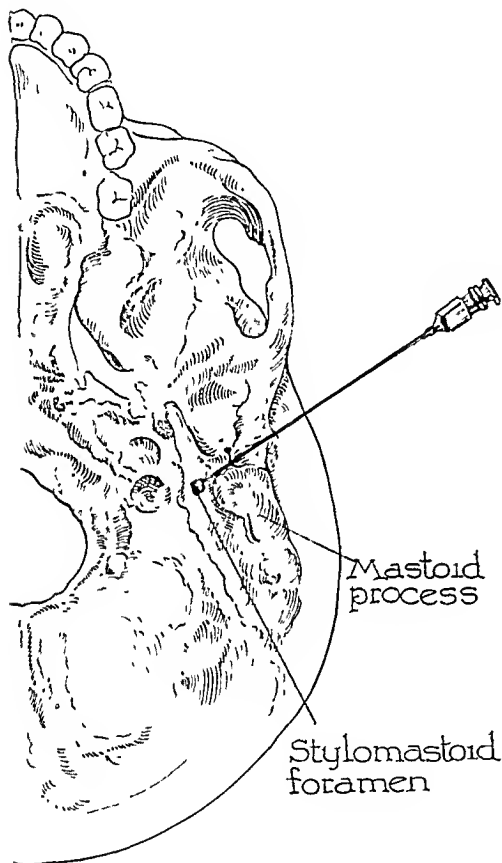


FIG. 148. Method of injecting alcohol into facial nerve as it emerges from stylomastoid foramen.

ward toward the stylomastoid foramen. When the stylomastoid groove is felt, 0.3 to 0.4 cc. of 50 per cent alcohol is slowly injected. If immediate weakness occurs, the injection is stopped. If no change is noted after 0.4 cc. of alcohol has been injected, one should wait for at least 30 minutes before injecting more, as the pa-

ralysis may be slow in appearing. The seventh nerve can also be injected by a posterior approach, as described by Whillis. The authors have not had personal experience with this method.

### COMPLETE OR PARTIAL SECTION OF BRANCHES OF SEVENTH NERVE

A method more certain than alcoholic injection is crushing or severance of the branches of the seventh nerve. Under local or general anesthesia the branches of the nerve are exposed just as they emerge from the parotid gland. The incision is started at the zygoma 1 cm. in front of the ear and is curved downward and backward so as to pass just under the lobule of the ear (Fig. 149). The main trunk of the nerve supplying the muscles of the upper part of the face is cut. It is desirable to spare the mandibular branch of the nerve to minimize the deformity. Various writers have advised suturing the nerve after severing it so that regeneration will take place. This gives the patient a second opportunity to decide whether or not he prefers the facial tic or the facial paralysis. German has recommended partial section of the branches of the seventh nerve as a means of diminishing muscle twitching without producing complete facial paralysis. Although the motor tic returns with regeneration of the nerve, repeated operations are feasible.

Under local or general anesthesia the anterior border of the parotid gland is exposed through a vertical or curving incision made just anterior to the ear. The several primary branches of the seventh nerve are isolated as they leave the parotid gland. Electrical stimulation identifies the branch or branches responsible for the facial tic. The nerve is divided through three-quarters of its diameter (Fig. 149). Regeneration can probably be delayed by anchoring the severed portion of the nerve as far as possible from the distal segment.

SECTION OF SEVENTH NERVE AND
ANASTOMOSIS WITH ELEVENTH
OR TWELFTH NERVE FOR
FACIAL TIC OR SPASM

The permanent treatment for violent and unsightly facial tic is surgical section of the facial nerve near the stylomastoid foramen and anastomosis of the peripheral stump with the eleventh or twelfth nerve
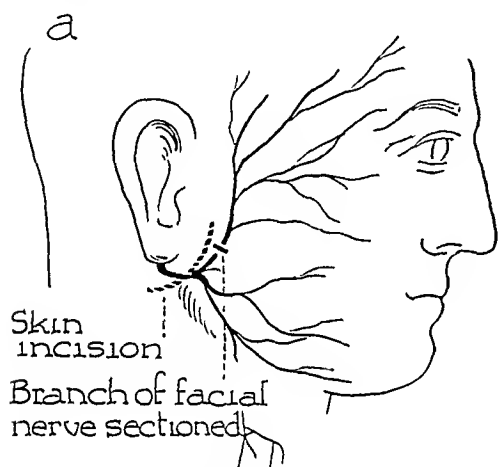
must be used, and it is best to do the operations four or five months apart.

## SURGICAL CORRECTION OF FACIAL PARALYSIS

There are numerous causes for permanent facial paralysis of the peripheral type. Among them are stab wounds, bullet wounds, and operations for tumor of the
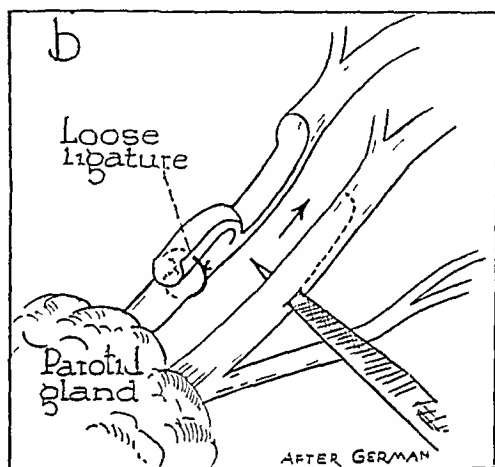


FIG. 149. An incision is made in front of ear to expose facial nerve as it emerges from parotid gland. One or several of the branches may be severed. It is desirable to spare branches going to lower part of face if they are not involved by the tic. (b) German's method of partial section of branches of facial nerve. Only three-fourths of nerve is severed to avoid total paralysis of muscles. Severed portion of nerve is reflected backward and anchored with a loose suture in order to delay regeneration.

as described below. By this procedure function or partial function of the facial muscles is obtained after five months. The authors, however, prefer facial-spinal accessory anastomosis, believing that the slight drooping of the shoulder which may follow sacrifice of the eleventh nerve is preferable to the hemiatrophy of the tongue that follows section of the twelfth nerve Theoretically, the twelfth nerve should be the better as the brain centers for the tongue and face are close together. Practically, this anatomic fact has proved of no special value in the re-education of the facial muscles after anastomosis. In severe bilateral tic or spasm the twelfth nerve on one side and the eleventh on the other

parotid gland. Infection of the middle ear and mastoid cells is an occasional cause, or the nerve may be destroyed during operation for mastoiditis. The nerve is almost always removed in the course of operation for acoustic neurinoma. Slowly progressive facial paralysis without other neurologic symptoms suggests an epidermoid within the temporal bone.

### NEUROLYSIS OF SEVENTH NERVE

On rare occasions, a neurolysis of the seventh nerve may be indicated. Stab wounds, for example, in the region of the parotid gland can be followed by slow strangulation of the seventh nerve by scar tissue. If freeing the nerve from scar tissue

is attempted, the nerve should first be exposed central and distal to the scar, even though this requires splitting of the parotid gland or removal of some of the mastoid process.

## End-to-end Suture of Divided Facial Nerve

When the facial nerve is severed by a stab wound central to the parotid gland or within the gland, an attempt at repair should be made within a few hours if possible, certainly at the earliest opportunity. Good results are less likely to be obtained after many months or years because of dense scar tissue around the nerve ends and because of fibrosis of the facial muscles. Since nothing is accomplished by an anastomosis under tension, it may be necessary to mobilize the nerve by exposing it well into the parotid gland or into the facial canal. The latter step requires removal of part of the mastoid process. Anastomosis of the distal and proximal segments, after excision of any damaged portion at each end, is made by a single through-and-through suture of fine silk.

## Facial-accessory Anastomosis

Permanent paralysis of the muscles of the face may be overcome by anastomosing the seventh nerve with the eleventh or twelfth cranial nerve. General anesthesia is desirable. The incision should extend from the base of the mastoid process downward in a curve parallel to the jaw. After the platysma muscle and the deep fascia have been opened, the parotid gland is retracted forward and the posterior belly of the digastric muscle is retracted downward. The nerve to this muscle enters its medial surface. If this branch is followed upward it will lead to the main trunk of the facial nerve as it passes from the stylomastoid foramen to the parotid gland. The facial nerve should be cut as near as possible to the foramen. The eleventh nerve is

now sought where it enters the body of the sternocleidomastoideus on its medial aspect at the junction of its upper and middle third. Once identified, the eleventh nerve is mobilized for at least 5 cm. and then cut with a knife at its point of entrance into the sternomastoid muscle. It is now possible to make an end-to-end anastomosis without tension, using one or two silk sutures or a plasma clot.

## Facial-hypoglossal Anastomosis

Instead of using the eleventh nerve, the twelfth nerve can be located as it passes over the cornu of the hyoid bone and mobilized toward the tongue for a distance of several centimeters (Fig. 150). It is severed near the base of the tongue just central to the point at which it divides into its branches. At the time this is done the ansa hypoglossi can be cut and anastomosed to the peripheral end of the twelfth nerve, but this is probably not worth while. The central end of the twelfth nerve is then drawn upward, with or without passing it under the occipital artery and digastric muscle, and sutured to the peripheral end of the seventh nerve.

If the eleventh nerve is used to innervate the facial muscles there will be permanent paralysis of the sternocleidomastoid and the upper fibers of the trapezius. This results in slight deformity but no discomfort. At first the facial muscles contract when the patient attempts to turn the head or shrug the shoulders, but in time a new motor pattern is set up in the cerebral cortex. If the twelfth nerve is used there will be atrophy of the corresponding half of the tongue. This causes no change in speech and no discomfort. It is not possible to recommend one operation as superior to the other. The operation should be done as early as possible after destruction of the seventh nerve during removal of acoustic neurinomas. It should be performed in all other types of peripheral facial paralysis as

soon as it is certain that there will not be spontaneous recovery of the nerve. This may mean a delay of six months between the onset of paralysis and the reparative operation. Some surgeons sever the cervical sympathetic chain at the time of anastomosis to narrow the palpable fissure.

part of the body, a great deal should not be hoped for. Nevertheless this much can be said for it: if the graft fails to result in return of function it has in no way interferred with the subsequent anastomosis between the seventh and the eleventh or twelfth nerves.
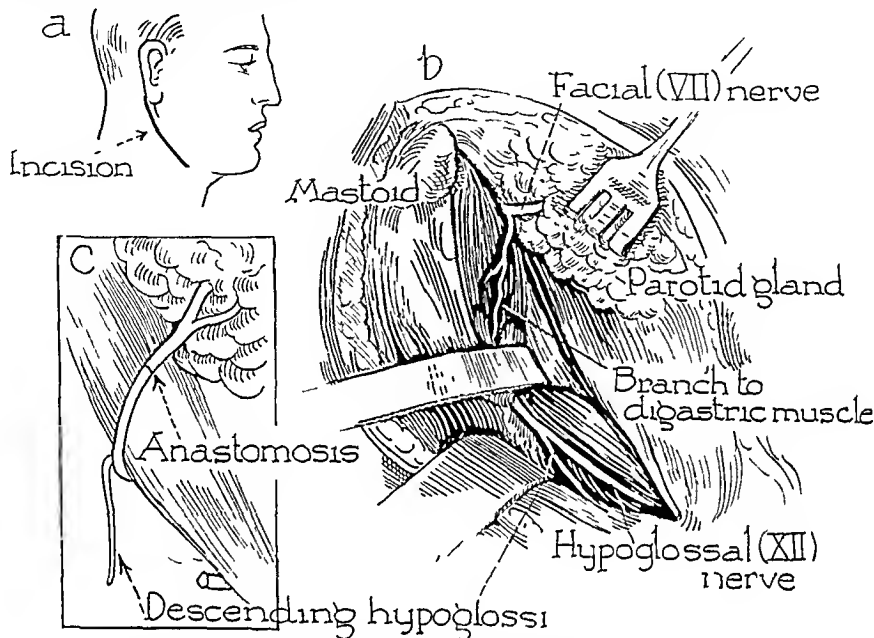


FIG. 150. Anastomosis of central end of hypoglossal nerve with peripheral end of facial nerve. (b) It is sometimes difficult to find facial nerve unless branch supplying posterior belly of digastric muscle is located and traced upward to main trunk. Hypoglossal should be traced toward tongue and severed just before it divides. Descendens hypoglossi should be sacrificed if it interferes with transposition of hypoglossal. (c) Hypoglossal nerve has been joined to seventh nerve; they lie on posterior belly of digastric muscle. Twelfth nerve is brought under this muscle in some cases. Descendens hypoglossi can be anastomosed to peripheral end of hypoglossal, but this is a procedure of doubtful value.

### NERVE GRAFTING FOR FACIAL PARALYSIS

If the seventh nerve has been destroyed during mastoidectomy, the placing of a graft in the facial canal may result in recovery of muscle function. This procedure, which is technically difficult, has not found wide favor. However, it may prove to be important. Inasmuch as nerve grafting is a physiologically poor procedure in any

Plastic surgeons have devised methods for correcting the displeasing appearance of complete facial paralysis, but these are not justified until anastomosis with another nerve has been tried.

### MÉNIÈRE'S DISEASE

There are many types and degrees and innumerable causes of pathologic vertigo. Of all this group, Ménière's disease and

traumatic aural vertigo are the only varieties with which the neurosurgeon is concerned. Ménière's disease is characterized by explosive attacks of violent dizziness associated with nausea and vomiting together with deafness and tinnitus which is predominantly unilateral.

In Ménière's disease the attacks of vertigo usually begin suddenly, with or without a warning aura. The room may seem to turn or the patient may feel that he is spinning. The patient may have the sensation of being pulled or thrown to one side. There may be a tendency to fall forward or backward. The vertigo is of the oscillating type and so severe that the patient must hold on to something to keep from falling. Often the patient feels safe only when lying flat on his back. The explosiveness of severe attacks of vertigo may give the impression of knocking the patient down. The attacks may last for several minutes, hours, or days. The average seizure lasts for from 20 minutes to two hours. Pallor, weakness, nausea, and vomiting occur in the violent attacks. There even may be mental confusion or fainting. An essential feature of the disease is that each attack eventually stops completely, leaving the patient free of dizziness. The remissions may last for hours, days, or years, but the periods of remission gradually become shorter.

In advanced cases there may be mild and more or less continuous giddiness between attacks. Tinnitus practically always is present in a more or less severe degree. It is described as ringing, buzzing, humming, or like escaping steam. It becomes worse during a paroxysm and may be described as roaring. Tinnitus may precede the first attack of vertigo by several years, but sometimes it is not noted until after the first attack. It may disappear or become scarcely discernible between seizures, but in general is constantly present and gradually grows more intense. The patient is usually able to lateralize this symptom. Tinnitus is sometimes bilateral but more pronounced on one side.

Slowly progressive deafness is usually present in this disease. Sudden deafness is unusual. A mild degree of deafness may be present for years before the first attack of vertigo. Often the patient is unaware of any deafness before the first attack. Even in long-standing cases the deafness may be a minor feature. There is often deafness of a lesser degree in the other ear. The vertigo, deafness, and tinnitus may appear at about the same time or in any order, months or years apart. The term "pseudo-Ménière's disease" has been used to indicate characteristic attacks of explosive vertigo without deafness and tinnitus.

This is almost exclusively a disease of middle age or more advanced years and probably is more common in males. The disease is rare, being about one-tenth as common as trigeminal neuralgia.

## ETIOLOGY

Probably there are several causes for the syndrome known as chronic Ménière's disease. Certainly, the etiology is unknown in most instances. Among the suggested etiologic factors are: arterial loops lying on the auditory nerve and other similar anatomic variations, degeneration of the nerve, and hydrops of the endolymph system as a result of a vasomotor imbalance or a disturbance in sodium metabolism.

## DIAGNOSIS

The diagnosis of Ménière's disease is made almost entirely from the history. A patient with unilateral tinnitus, partial deafness, and attacks of violent vertigo probably has Ménière's disease. An acoustic neuroma or other tumor in the cerebellopontile angle must be ruled out by careful neurologic studies and x-ray examination of the petrous bone. As the disease is sometimes bilateral (at least 10 per cent), it

may be difficult to determine the proper side for operation. To determine the side of the disease, the patient must be carefully questioned as to the side of the loudest tinnitus and the greatest deafness. Audiograms and vestibular tests should be made in all cases even though the latter are often normal.

When medical therapy such as a diet low in sodium together with large doses of ammonium chloride (Furstenberg, Laschmit, and Lathrop), the low-salt, low-fluid intake (Mygind and Dederding), the high potassium chloride intake (Talbot and Brown), histamine acid phosphate intravenously (Shelden and Horton), or nicotinic acid and thiamine chloride are ineffective in controlling the attacks of vertigo, surgical treatment is indicated. Of the various operations devised, section or partial section of the acoustic nerve has been the most popular and reliable. Alternative procedures such as destruction of the labyrinth by alcoholic injection, exenteration of the semicircular canals, electrosurgical destruction of the vestibular ganglion (Putnam), and surgical opening of the ductus vestibuli (Portmann and Woodman) have not been as successful as eighth-nerve section.

### Technic of Eighth-nerve Section

The preoperative preparation, anesthesia, and surgical exposure of the acoustic nerve are the same as described for operation on the fifth nerve by the cerebellar approach. If the opening in the skull has been properly placed, little retraction of the cerebellum is required to bring the eighth nerve into immediate view using a lighted retractor. By gentle manipulation the eighth nerve is freed from the arachnoid of the lateral cistern. With a blunt right-angled hook, the eighth nerve is carefully picked up, thus separating it from the nervus intermedius and the seventh nerve, which are hidden under the eighth nerve (Fig. 151). This requires great care since a

slight pull on the seventh nerve may result in temporary facial paralysis. A large arterial loop is usually found lying on or adjacent to the eighth nerve. This can usually be pushed to one side. If the patient is almost totally deaf on the side of the operation, the eighth nerve is completely divided with a right-angled knife or scissors. If the patient still has useful hearing, only the anterior half of the nerve is cut. Sometimes the auditory and vestibular branches of the nerve are distinctly separate. The vestibular fibers comprising the anterior half of the nerve are readily divided, either fiber by fiber or in mass, with a sharp-pointed right-angled knife. If distressing tinnitus is present the two adjacent fibers of the auditory portion should also be sectioned. This procedure has given complete relief of a high-pitched tinnitus with preservation of useful hearing. The dura is then closed with interrupted sutures of fine silk, and the muscle and skin incision in the usual way.

Postoperatively the patient is permitted to lie in any position but is encouraged to use the back rest most of the time and may be up in a chair at the end of a week. The average person leaves the hospital on the twelfth postoperative day.

### Complications and Results

If the eighth nerve has been completely sectioned, permanent total deafness results. If only the vestibular fibers are sectioned hearing will be the same as before operation. Improvement in hearing after operation has been reported. If the seventh nerve is injured, there will be facial weakness or paralysis. Headache is often present during the first few postoperative days because of loss of cerebrospinal fluid. The chief complication of the operation is a new type of vertigo. This dizziness results from cutting off the vestibular mechanism from its connection in the brain stem, thus throwing the entire burden of maintaining

equilibrium on the opposite vestibular apparatus. This postoperative dizziness may not subside completely for a number of days or weeks. Usually, however, complete freedom from dizziness is eventually obtained.

There is no disturbance such as ataxia. After bilateral section of the vestibular portion of the nerve, which is rarely performed, there is a visual sensation described as "jumbling of objects" when the

creased or unaltered. Often Ménière's disease is a bilateral affliction, and, years after sectioning the vestibular nerve on one side, the disease may develop fully on the opposite side.

## EIGHTH-NERVE SECTION FOR TRAUMATIC VERTIGO OR INCAPACITATING TINNITUS

Section of the eighth nerve or its ves-
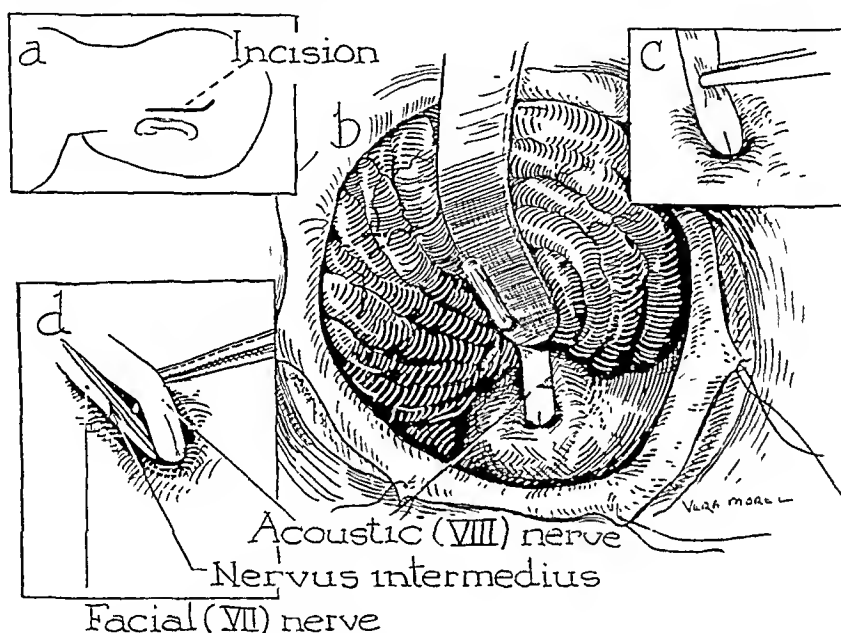


FIG. 151. Eighth-nerve section for Ménière's disease. (b) Eighth nerve hides seventh nerve from view but their relationship is shown in (d). (c) If some of the auditory fibers are to be spared, only the anterior one-half of the nerve should be severed. (d) Auditory nerve has been elevated with a hook to expose underlying facial nerve and nervus intermedius. Latter has diameter of a hair.

patient is in motion. Also there is uncertainty when walking in the dark. Both of these symptoms persist but diminish. The diplopia sometimes experienced after eighth-nerve section is always transient. The patient is completely and permanently relieved of the attacks of vertigo provided they originated on the side of operation. The tinnitus disappears completely in only 50 per cent of cases. In the others, it is de-

tibular portion is rarely performed except for the relief of Ménière's disease. Other types of vertigo are either not severe enough to justify operation or would not be remedied by the procedure. There are rare exceptions to this statement. An occasional patient may be incapacitated by more or less constant vertigo following a fracture through the petrous portion of the temporal bone. Partial deafness and some-

times facial paralysis are associated. Total section of the eighth nerve in such a case is justified if the condition is chronic. This syndrome should not be confused with the vague dizziness complained of by a high percentage of persons who have had head injuries.

Another indication for section of the eighth nerve is incapacitating tinnitus. A patient may suffer greatly because of the loudness of the noise in one ear. Complete or partial deafness may be associated. Vertigo, if present, is a minor consideration. This condition may be the result of syphilis or trauma. Although section of the eighth nerve does not always relieve the tinnitus of Ménière's disease, it may nevertheless completely or almost completely stop the ear noise in the cases of this type. In cases of bilateral exasperating tinnitus and partial deafness, there is little to be accomplished by unilateral eighth-nerve section and only rarely is a patient willing to accept total deafness in exchange for relief of tinnitus. The tinnitus often complained of by the aged is probably on an arteriosclerotic basis and such patients should not be operated upon.

## GLOSSOPHARYNGEAL NEURALGIA

Glossopharyngeal neuralgia, also called tic douloureux of the ninth nerve, is characterized by recurring attacks of excruciating pain in the region of the tonsil, posterior pharynx, back of the tongue, and middle ear. The pain is identical in character with the pain of trigeminal neuralgia, and has frequently been mistaken for neuralgia of the mandibular division of the trigeminus.

differences are in the distribution of the pain and in the location of the trigger zone. The first manifestation of the disease is a flash of pain in the region of the tonsil or ear. The pain, which is stabbing in character, may last for a few seconds or possibly a minute or two. The patient is left breathless and astounded. The second attack may not occur for weeks, months, or years, but other attacks always do occur and with increasing frequency and severity. The patient soon realizes that swallowing sets off the seizures and when the attacks are occurring frequently, takes only liquid nourishment. When eating, he tilts the head to one side so that the food will not touch the trigger zone. If a violent attack occurs during the meal, the patient begins to eat rapidly in an effort to finish the meal during the latent period which follows an attack. Due to the severity of the pain induced by swallowing, the patient may become cachectic. Some patients push a finger into the auditory meatus during each paroxysm, a gesture never made by patients with trigeminal neuralgia. In some cases, movement of the tongue in talking stimulates an attack and the patient is forced to communicate by writing. Yawning or clearing the throat may also precipitate a paroxysm. Between seizures, however, the patient is without complaints. As in trigeminal neuralgia, glossopharyngeal neuralgia is characterized by spontaneous remissions which may last for weeks or months, and during these intervals the trigger zone disappears.

It is usually unilateral, but it may be bilateral and in a number of cases has been associated with trigeminal neuralgia.

### DIAGNOSIS

Once the surgeon has heard the description of the pain or has witnessed a seizure, no doubt exists as to the diagnosis of paroxysmal neuralgia. The real problem, however, lies in deciding whether the patient

thetic eliminates the trigger zone in the pharynx but does not eliminate the pain in the ear. In such a case, according to Spurling and Grantham, but not in the authors' experience, the upper two rootlets of the vagus nerve as well as the glossopharyngeal nerve should be cut if relief of all pain is to be obtained.

Tumors and inflammatory processes involving the ninth nerve in or near the
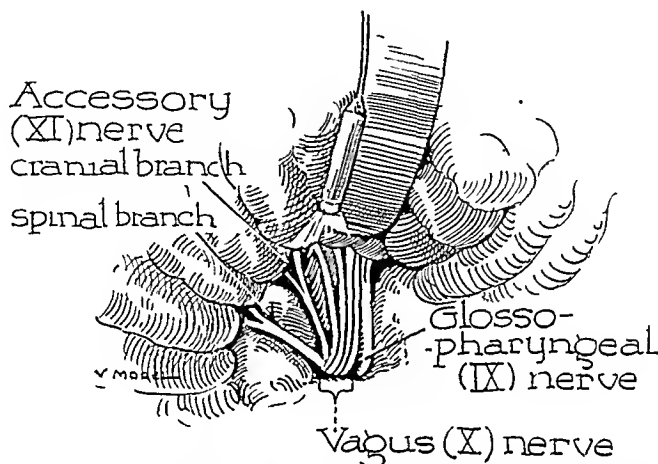


FIG. 152. Exposure of ninth, tenth, and eleventh nerves. Glossopharyngeal nerve (IX) is sometimes composed of two or more filaments.

has fifth-nerve neuralgia or ninth-nerve neuralgia, or both. It may be difficult, from the patient's statements, to ascertain whether the patient has pain in the tonsil, the base of the tongue, or the pharynx, or whether he has pain along the mandibular division of the trigeminal nerve. In such cases stimulation of the ninth nerve by touching the tonsil or posterior pharynx with a cotton applicator will usually precipitate an attack. To verify this finding the tonsil, pharynx, and back of the tongue may be sprayed with 1 per cent pontocaine. As soon as the mucous membrane becomes anesthetized the trigger zone disappears, and during this period of anesthesia the patient finds that he can talk and swallow in comfort. In an occasional case the anes-

jugular foramen are invariably evidenced by involvement of the adjacent vagus nerve.

### INTRACRANIAL SECTION OF GLOSSOPHARYNGEAL NERVE

The ninth nerve is exposed through an opening identical with that used for cutting the fifth nerve by the cerebellar approach. A sheet of wet cotton is laid on the exposed cerebellum which is gently retracted upward, immediately exposing the ninth, tenth, and eleventh nerves as they enter the jugular foramen (Fig. 152). The ninth nerve may consist of a single rootlet, but close inspection may show that it is made up of two or more strands. It is the nerve nearest to the acoustic nerve and is the

most anterior of the group of nerves which enter the jugular foramen. At the foramen the ninth nerve is separated from the rootlets of the vagus nerve by a dural septum The ninth nerve should be gently separated from the arachnoid and divided close to the foramen with a sharp right-angled knife. The patient suffers a sudden severe pain in the pharynx when this is done. The lighted retractor is then withdrawn, the protective cotton removed, and the dura closed with interrupted sutures of cotton or silk.

In the patient with a short thick neck, exposure of the skull may be somewhat difficult. The intracranial portion of the operation, however, is the simplest of all operations performed in the posterior fossa of the skull.

Since most of these patients are past 50 years of age, it is desirable that they sit up with a back rest on the first postoperative day. Fluids and food may be given as soon as the patient desires. There is no objection to permitting the patient to sit up in a chair on the third postoperative day. The sutures may be removed on the third or fourth day. The average patient is ready to leave the hospital on the seventh postoperative day.

Because the nerve has been sectioned central to its sensory ganglia, there can be no regeneration. The mucous membrane supplied by the ninth nerve remains anesthetic for the balance of the patient's life and the gag reflex on the side of the operation is lost. There is no disturbance in swallowing or phonation unless some of the vagus rootlets have been injured. No motor weakness can be demonstrated These patients are unaware of the numbness of one side of the pharynx and never have residual symptoms of any kind. The loss of taste sense on the posterior third of one side of the tongue is not noticed by the patient. Results are usually very satisfactory.

## OTHER INDICATIONS FOR GLOSSOPHARYNGEAL-NERVE SECTION

Sectioning of the ninth nerve for the relief of intractable pain due to carcinoma has been discussed elsewhere in this chapter. Section of this nerve has also been advocated for the relief of a carotid sinus syndrome. Although denervation of the carotid sinus in the neck is a simple and usually adequate procedure, intracranial section of the glossopharyngeal nerve may prove to be a more complete and therefore preferable procedure. Ray has shown that ninth-nerve section is effective in relieving the symptoms produced by a hyperactive carotid sinus.

## OPERATIONS ON TENTH, ELEVENTH, AND TWELFTH CRANIAL NERVES

Sectioning of one or two rootlets of the vagus (tenth) for the relief of aural neuralgia and other types of pain has been advocated, but the evidence for such a procedure is at present certainly inadequate. Other indications for intracranial section of the vagus nerve do not exist. Repair of the recurrent laryngeal nerves by several methods has been reported. Section of one or both superior laryngeal nerves is sometimes performed in cases of painful tuberculosis or carcinoma of the larynx

The eleventh (accessory) and twelfth (hypoglossal) cranial nerves are utilized in the correction of facial paralysis as previously described. Peripheral or intracranial section of the eleventh nerve for torticollis is described in Chapter 15 A rare indication for severance of one hypoglossal nerve is painful athetosis of the tongue.

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# 15

# Diseases Characterized by Involuntary Movements

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## INTRODUCTION

The surgical treatment of the dyskinesias should rest on a basis of physiology. The dyskinesias susceptible to surgical treatment may be divided on a physiologic basis into two main groups, each produced at times by a variety of different disease processes. These groups are (1) alternating tremor (paralysis agitans),[1] and the athetoid syndrome (athetosis, torticollis, dystonia musculorum deformans, ballism, hemichorea, etc.).[2] It is important to distinguish sharply between them.[3,4]

## ATHETOSIS AND DYSTONIA

Manifestations. The two terms, athetosis and dystonia, refer to an apparently similar physiologic mechanism, which expresses itself in the former case by abnormal involuntary movements, in the latter by involuntary postures. Either or both may coexist with severe injury to the pyramidal tract, or with an alternating (parkinsonian) tremor. The disorder may affect the muscles of articulation alone, the face, the neck alone (torticollis), one extremity (Fig. 153), both extremities of one side, both arms, the trunk, or almost the entire skeletal musculature (Fig. 154). Ordinary clinical observation reveals at once that the involuntary movements (1) shift irregularly from one group of muscles to another, (2) that they

are increased by effort or emotion, (3) that the contractions are smooth, powerful, and sustained, and (4) that there is simultaneous innervation of agonists and antagonists.[4] The fingers are ordinarily extended on the hand, and the great toe on the foot, in a posture wholly unlike that of hemiplegia. The movements cause a great output of energy, sweating, and a marked rise in oxygen consumption unlike the tremor of paralysis agitans (Fig. 156).

Electromyographic studies show further that there is an asynchronous discharge of motor units resembling that of normal voluntary innervation, except that it is not within reach of volition, and that there is no normal relaxation of the opposing muscles[4]; hence, of course, the squirming and distortion. Such studies are of value in differential diagnosis between athetosis and tremor in doubtful cases, as will be described below under the heading of Tremor.

The abnormal movements and postures are not particularly affected by section of posterior roots, as are the other types of "spasticity" and "rigidity." This is one of the reasons for the present undeserved ill repute of posterior rhizotomy, which probably has a definite sphere of usefulness in other conditions. Nor are peripheral nerve sections effective, except in cases of tor-

ticollis; they are likely to lead merely to a reverse of the deformity. Fixation in splints or casts involves the danger of pressure sores.

The above brief review of the clinical physiology of athetosis makes it appear probable that the syndrome does not depend upon the release and exaggeration of predominantly local reflexes (as hemiplegic

Dystonia. The physiologic mechanism just described is seen in cases in which there is damage to certain portions of the basal ganglia: mesial and ventral portion of the thalamus, lenticular nucleus, corpus luysi, and occasionally red nucleus and the tracts leading to it from the cerebellum. The position of the lesion in relation to the pyramidal and extrapyramidal systems is
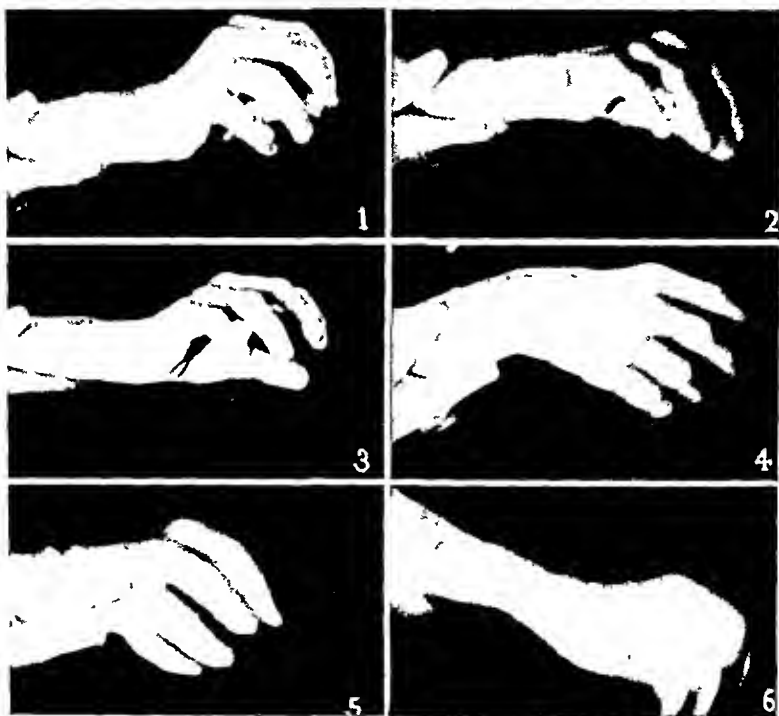


Fig. 153. Successive positions of hand, in a case of hemi-athetosis. From a moving-picture film, taken at 16 frames per second. Note irregular character of movement.

spasticity apparently does), but upon showers of impulses arising in higher centers as a response to afferent stimuli of many kinds. As the involuntary movements may take place in a hemiplegic extremity, they probably do not descend along the pyramidal tract. The results of treatment by section of extrapyramidal tracts and other physiologic means will be discussed below.

Clinical Varieties of Athetosis and

shown schematically in Fig. 157. Such injury may be produced in a number of ways.

The commonest etiology for the syndrome is birth injury. In 18 out of 38 cases observed by the author, there was a definite history of birth trauma, and the infant was immediately noticed to be paralyzed. In two cases of the series there was prematurity, and in one, hemorrhagic disease, with onset of symptoms seven months, 12 years and eight months, respectively, later.

Symptoms arose late in life, usually between the ages of eight and 20 in 12 cases. In two of these the diseases were familial; in ten no etiology was discovered.

Athetosis may also accompany infectious and degenerative diseases and injury. In Hammond's first case it developed in the

Athetosis was included in Gould and Pyle's Dictionary of Curiosities of Medicine (1898). It is, however, by no means a rare disease. No reliable statistics are available, but the incidence of birth injuries in general is probably greater than that of poliomyelitis, and at a rough esti-
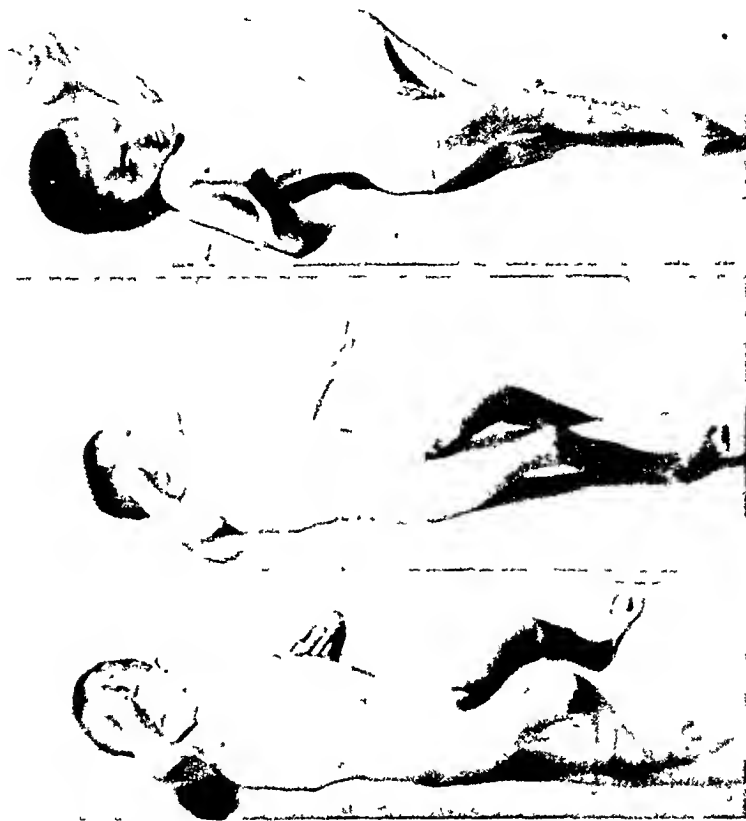


FIG. 154. Successive positions in a case of severe bilateral athetosis and dystonia. From a moving picture.

course of a hemiplegia following pneumonia,[5] and instances have been reported in the course of encephalitis, multiple sclerosis, and injury. Five such cases happen to be included in the author's series. It is extremely rare to have athetosis (or paralysis agitans) result from a tumor. A "hemiballism" may, however, occur following metastasis to the body of Luys.

mate, between 10 and 25 per cent of cases of birth injury result in athetosis and dystonia. The dry statistics and bare physiologic description of cases give no adequate picture of the misery which the disease produces. In its severer forms it is usually a bar not only to self-support, but also to almost every form of social intercourse and enjoyment. The patients, many of whom

are intelligent, are often taken to be mentally deficient, or are confined to institutions for the feeble-minded for lack of other possible disposition. There are few diseases which are more distressing, and advances in treatment are urgently needed.

Treatment of Athetosis: Retraining Drugs. Athetosis has in the past been considered a neurosis, and torticollis is still so considered by ·many. There is no doubt



Fig. 155. Same patient as shown in Fig. 154 after section of anterior columns and anterior roots.

that the abnormal movements are usually greatly increased by emotional strain and excitement, and patients are often improved by the cultivation of serenity and resignation, for example, by psychoanalysis.[6]

Actual muscle training and special exercises have been of benefit in certain cases. Exactly what principles are involved, and what cases may expect substantial relief, is by no means as clear as is the situation in regard to poliomyelitis. Improvement of strength or nutrition of muscles is seldom necessary. What is needed is relaxation, and this is difficult to teach. The methods to be employed, and the qualitative results obtainable, are outlined in the publications of Carlson[7] and of Phelps.[8] Unfortunately, no statistical analysis of a series of cases has yet been presented. Such measures are always worth trying, and if they are successful nothing more drastic need be considered, but a considerable proportion of even the willing and intelligent patients fail to obtain much benefit after years of patient effort in specialized clinics.

Drug therapy has been entirely unsuccessful in the past. Bucy[9] has shown that anesthetic doses of pentobarbital produce a depression of abnormal movements lasting for two days. West[10] in England and Burman[11] in this country have reported interesting results with curare, which produces a relaxation of hemiplegic spasticity and athetoid movements lasting sometimes for several days. The treatment is not yet on a practical basis. From attempts to repeat their work at the author's clinic, it appears that proper preparations are difficult to obtain, that the therapeutic index is low, and that the effects are evanescent. It is possible that more will be accomplished in the future. Hassin[12] reports improvement from the use of quinine in two cases of athetosis and one of torticollis. It has been without effect in the 11 cases in which it was used by the author. Doses of hyoscine large enough to produce confusion do not arrest the movements, but (usually) control hysterical phenomena.

Operative Treatment; Orthopedic. On the whole, little is accomplished for the athetoid syndrome by peripheral operations on muscles or nerves. Posterior root section and operations of the Stoffel type are definitely contraindicated. Stabilization of the ankle or tenotomy of the Achilles

tendon is sometimes of benefit; it should, however, be deferred until neurosurgical procedures have been carried out, if any are contemplated. External fixation of the affected extremities is seldom practicable.

Neurosurgical Treatment; Cortical Operations. The first successful operation for athetosis was reported by Horsley in 1909.[13] In a case involving one arm he resected the anterior portion of the corresponding "motor" cortex with relief of the abnormal movements, which were replaced by an incomplete paralysis and a sensory loss. Successful operations of this type have

precentral *convolution*. The specimen appears to consist of "transitional" cortex in Campbell's terms, or Area 6 according to Brodman. A further careful study has been reported by Bucy and his collaborators.[9,17] In two of their cases the symptoms were ameliorated by removal of apparently a smaller portion of Area 6, and the disability was less than that reported by Horsley. This experience has also been reported by Klemme,[19] who removes only nonexcitable cortex anterior to the precentral convolution, but the details of his cases are not yet available.
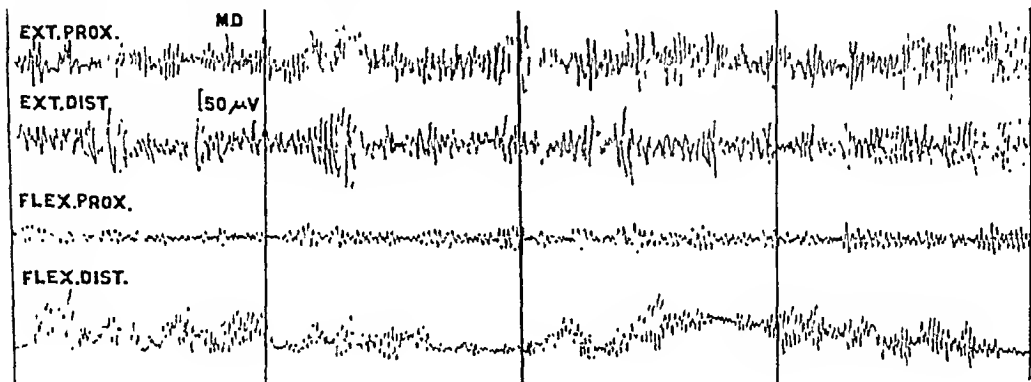


FIG. 156. Electromyograms from a case of athetosis. Note that stream of impulses varies irregularly in different positions of same muscle, and that opposing muscles contract simultaneously. Vertical lines denote time in seconds. (Courtesy, Dr. Paul Hoefer.)

been reported by Anschütz,[14] Payr,[15] Nazaroff,[16] Bucy and collaborators,[17] Sachs,[18] Klemme[19] and others; unsuccessful ones by Spiller, Frazier and Van Kaathoven,[20] Forester,[21] Naffziger,[22] Mashanskiy,[23] and others. Some unsuccessful cases have gone unreported.

The precise *extent of cortex* which should be removed remains to be determined. In Horsley's case the anterior part of the "electrically excitable" cortex was resected. It is clear from his description that the incision was not carried into the depths of the central sulcus and part way up its posterior surface, where the Betz-cell area extends, but was restricted to the

In the third of Bucy's cases, however, removal of Area 6 did not adequately control the abnormal movements. From the work of Bucy, who has given much thought to the subject, it would seem that cortical operations should be reserved for unilateral cases in which the affected extremity is already useless on account of paralysis as well as because of the abnormal movements. A further limitation to the use of cortical extirpations would seem to be that if the leg is involved the procedure becomes extensive, and that operations to relieve involvement of the right side of the neck or face endanger the speech area. The possibility that convulsions will be precipi-

tated by the resulting scar should not be forgotten.

Cortical operations have, on the other hand, certain advantages over the operations on the spinal cord, to be described

sexual activity, as chordotomies may to a slight extent.

Preparations for Operation. It is important to have good motion-picture records before and after any operation for dys-
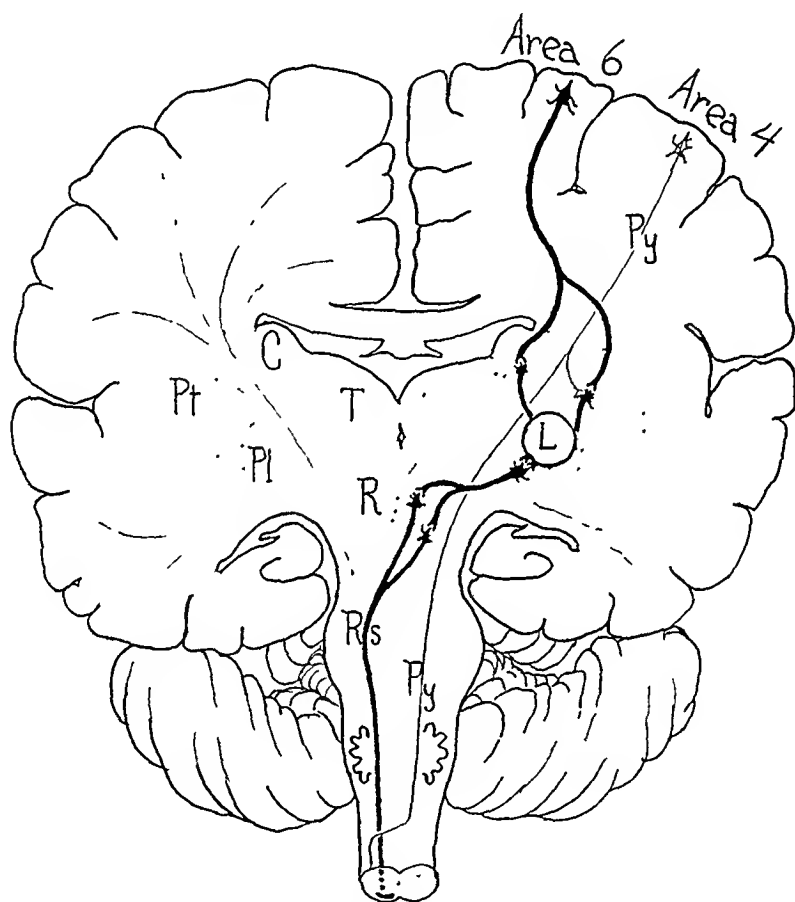


FIG. 157. Diagram of extrapyramidal chain of neurons (heaviest lines) and usual site of lesion in cases of athetosis and dystonia, in their relation to other structures. (C) Caudate nucleus, (L) lesion, (Pl) globus pallidus, (Pt) putamen, (Py) pyramidal tract, (R) reticular substance, (Rs) reticulospinal tracts, (T) thalamus. (Putnam,[2] T. J., Journal of Bone and Joint Surgery, 21.952.)

below. In the first place, they are technically easier, and safer except in extremely specialized clinics. In the second place, they permit an attack on symptoms involving one arm alone, without affecting the leg. In the third place, they do not endanger sensation, control of the bladder, and

kinesia. The patient, his physician, and his family are all too apt to forget the severity of the preoperative conditions. Electromyograms form a useful record. A carefully taken basal metabolism before and after operation gives an index of how much has been accomplished. Encephalograms are

rarely worth while. Before any extensive operation it is a good idea to start the patient on medication with ferrous sulfate, to build up a reserve of iron.

Technic of Cortical Extirpation. The following method of procedure, differing in some details from that of the authors cited above, is suggested as an unprejudiced method of determining the minimum cortical excision necessary to obtain relief in a given case of athetosis. The same method may be used in cases of tremor (see below). Such operations under local anesthesia suffer from the limitation that the abnormal movements are sometimes arrested by the basal anesthetic.

Morphine and hyoscine are an effective combination for basal anesthesia. A dose of 0.01 to 0.02 Gm. ($\frac{1}{4}$ to $\frac{1}{3}$ gr.) of morphine, with 0.5 mg. ($\frac{1}{100}$ gr.) of hyoscine is given four hours before the operation is begun. The morphine may be repeated at the time the patient is placed on the table. The entire head is shaved.

A flap is laid out as described in the chapter on operations for brain tumors. Compared to the flap ordinarily employed for tumor operations, it should be rather small (about 10 cm. in diameter) and placed so high that its midpoint overlaps the midline. The anterior edge should be within the hairline. The area of proposed incision is carefully infiltrated with procaine, special attention being given to the region of the temporal muscle. The incision is marked on the skin with a scalpel and draperies applied close to the edge of the wound.

The incision is carried down to the bone in the usual manner, bleeding being controlled by digital compression while each length of cut is being made, and subsequently by hemostatic forceps or skin clips. Five burr holes are drilled in the skull. Care should be taken in placing them that they do *not* approach closer than 1 cm. to the midline, for fear of encountering tribu-

taries to the sinus. The bridges of bone are cut with a wire saw. It is advantageous to make an especially long bevel near the vertex. The base of the flap is narrowed by means of Montenovesi forceps.

Breaking up the flap is apt to be the only painful part of the operation. The pain can be avoided by giving the patient a whiff of ethyl chloride or vinethane, or by giving a little evipal or pentothal intravenously.
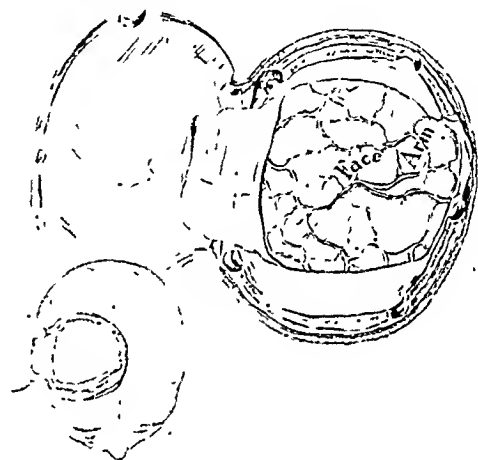


FIG. 158. Location of cortical center for movements of arm, adjacent to longitudinal sinus. Drawn from a photograph taken at operation.

The dura is incised along the vertex, and turned up toward the flap. It may be necessary to rongeur away a little of the edge of bone to expose the entrance of the rolandic vein into the longitudinal sinus. The "arm" area usually lies actually in contact with the sinus, at the vertex, and the "leg" area on the mesial surface—which one would scarcely guess from the usual diagrams (Fig. 158). (A special study has been devoted to this subject by Scarff.[24])

The representation of the body is mapped out by stimulation. Almost any form of stimulator will serve; the ordinary Harvard coil is satisfactory. On the whole,

"sharp" irregular currents are more effective than a sine wave. The current should be just strong enough to produce a twitch in the temporal muscle. A bipolar electrode (two stainless needles inserted into the wire cables of a rubber-covered lamp cord will do), is used to apply the current. Stimulation is begun at the anterior edge of the bony defect, and gradually carried backward until a response is obtained. Each region is marked with a sterile paper number, and the type of response recorded. Convulsive attacks are easily produced by prolonged stimulation (over a second) in any spot. They are usually harmless, but can be controlled with a little ethyl chloride or chloroform.

If, as is usually the case, the arm is the principal offending member, and if the abnormal movement is, by good fortune, still in progress, a direct experiment may be made to find how best to control it. Pressure is exerted with a spatula on a piece of cotton on one of the frontal convolutions exposed in the anterior portion of the wound. If there is no relief the pressure is repeated a little farther back, finally over the excitable cortex, or lips of the rolandic fissure. Pressure in this region should cause a weakness of the corresponding extremity, after a latent period of about three seconds. When an area is found, pressure on which regularly relieves the abnormal movements, about 1 cc. of 1 per cent procaine is injected into the corresponding region, in as narrow a strip as possible, and not deeper than 1 cm. If this maneuver results in a cessation of involuntary movements, the cortex may be excised. In this manner damage to the cortex and to the function of the corresponding extremity may be minimized.

What should be done if the involuntary movements have already been stopped by the anesthetic, or if the results of infiltration of the cortex are inconclusive? In the present state of information on the subject

the most conservative procedure would seem to be the removal of Area 6; namely, the extreme anterior edge of the electrically excitable area, usually at the summit of the precentral convolution.

Extirpation may be carried out with the cutting current, or by incising the pia, undermining it, and scooping out the underlying cortex (Horsley's method). Care should be taken (it appears at present) to remove only *cortex,* with as little subjacent white matter as possible; and to preserve visible blood vessels, in order to minimize damage and to be sure how much has been accomplished.

Closure is carried out by the standard method, described in Chapter 1.

A surgeon working in this new field should always be ready to reopen the wound and do a larger extirpation if the symptoms are not relieved at once or if they recur. This is most easily accomplished within a week of the original operation. Needless to say the patient and his relatives should be carefully prepared for such a possibility. The specimen removed should be promptly sectioned and examined to determine the type of cortex involved, and as a guide to possible further steps.

The administration of phenotoin in doses up to tolerance should be started before operation, and continued for at least a year afterwards.

**Treatment of Athetosis by Chordotomy.** In the most distressing cases of athetosis—the severe generalized or bilateral cases—treatment by excision of the cortical representation of *all* extremities is out of the question. It was for this group of cases that section of extrapyramidal pathways in the spinal cord was first proposed.[25] Subsequent experience has shown that such an operation is capable of providing substantial relief for milder cases also, with far less loss of voluntary power and control than must result from excision

of any of the electrically excitable cortex. Destruction of the region of the cord in which the extrapyramidal fibers lie, in the course of chordotomies for pain in patients with no motor defect, ordinarily leads to no disturbance of strength, control, or motility of the extremities.[26,27]

Section of the anterior column is not without its disadvantages, however. In severe generalized cases it may be one of the most complicated and difficult of all surgical operations, when the problems of anesthesia, hemostasis, exposure, selection of location of area to be destroyed, method of destruction, employment of root section, and after-care including use of a respirator and tidal drainage are considered. The mortality is high in the first cases of most series, and especially in adult cases in proportion to age.

The operation should never be undertaken unless a Drinker respirator is available. It may lead to a contralateral hemianesthesia, which may be bilateral if the operation is bilateral. Potency and sexual enjoyment may be diminished in the male. Altogether, it is a serious undertaking, which is justified only because the relief it affords cannot be provided in any other way except by sacrifice of motor power and control. Anterior root section for torticollis may be readily combined with it when indicated. Against its disadvantages should be weighed those of the cortical operation, especially in view of the fact that it is precisely in the milder unilateral cases suitable for treatment by cortical excision that chordotomy is safest and easiest.

The theoretical basis of the operation has been given in detail elsewhere,[25] and need be reviewed only briefly here. Its aim is to interrupt abnormal motor impulses transmitted over nonpyramidal pathways. Anatomic studies show that these lie chiefly in the anterior column of the cord, between anterior roots and central sulcus, chiefly superficial (Fig. 159). Practical ex-

perience has confirmed the correctness of the hypothesis, and has shown that the few extrapyramidal fibers scattered through the remainder of the cord are of small importance.

The site and extent of the operation must be carefully considered in each case. If the arm and leg of one side are involved alone or predominantly, with no torticollis, a high unilateral cervical section is indicated
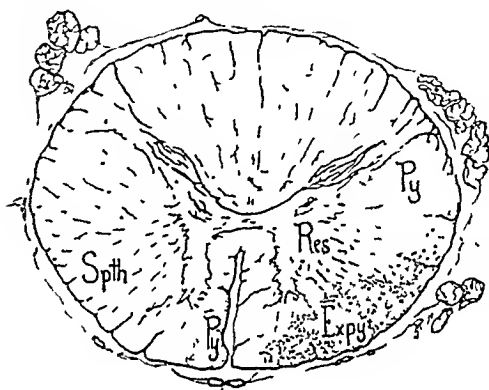


FIG. 159. Diagram of principal pathways in cervical cord drawn from an actual specimen of degeneration of pyramidal tract, modified according to cases published by Obersteiner and Thomas. (Expy) Extrapyramidal tracts (coarse stipple), (Py) pyramidal tract (fine stipple), (Res) respiratory tract, (Spth) spinothalamic tract. (Putnam,[2] T. J., Journal of Bone and Joint Surgery, 21:952.)

If all four extremities are involved, the worse side should be operated upon first, then the other after an interval of from 4 to 12 months. If torticollis is severe an anterior root section (described below) is performed as a first step, then a section of one anterior column if the patient's condition warrants it. The order of procedure should not be reversed, as the torticollis interferes with healing of the wound. If the leg alone is involved, which is rare, section of the anterior column may be carried out at a site

of election in the thoracic region—a relatively safe and easy procedure.

**Technic of Cervical Chordotomy for Athetosis.** Tribromethanol or sodium-pentobarbital anesthesia is suitable. The use of ether should be reduced to a minimum, but may be necessitated by persistence of the involuntary movements under the anesthetic.

The patient is placed face down on a cerebellar head rest, with the neck extended. The neck is shaved to 5 cm. above the external occipital protuberance. It is given a scrub with 70 per cent alcohol, followed by bichloride solution. The subcutaneous tissues and muscles down to the periosteum are infiltrated with 1 per cent procaine, and the site of the incision is scratched on the skin from the occipital protuberance to the tip of the vertebra prominens. Draperies are then applied close to the edge of the incision.

The wound is made directly in the midline, while hemorrhage is controlled by deep pressure by the assistants' fingers. Vessels are snapped, but the snaps in each layer are touched with the coagulating current and removed before the next layer is incised. The spines of the vertebrae are used as a guide to the midline. Retraction is maintained by means of a Gelpi perineal retractor at each end of the wound.

As soon as one of the vertebral spines is exposed, a light dissecting current is used to clean one side of it, and to expose the next spine. This is a particularly advantageous method of dealing with the bifid spines of the cervical vertebrae. Hot wet strips of gauze are progressively tucked into the slit thus made. When one side of the spines is cleaned and packed, the other side is treated in the same way. Usually the second to the fifth spines are so exposed. Next, the muscle mass is retracted on one side and the laminae also cleaned with the cutting current, aided by a broad periosteal elevator. The other side is similarly treated. The second to fourth spines are than removed with laminectomy shears.

When bleeding has been well controlled the laminae themselves are removed. The extent of removal depends upon what it is intended to accomplish. If a simple unilateral anterior chordotomy is all that is intended, about half of the fourth lamina is removed, well out toward the pedicles on the side which is to be operated upon, but little beyond the midline on the other. The exposure is enlarged by rongeuring away the adjacent edges of the laminae on either side. This opening permits section of anterior roots in the segments above and below.

If, on the other hand, the important part of the operation is the Foerster-Dandy procedure for torticollis (described below), a much more extensive bilateral laminectomy must be undertaken, removing all of both sides of the first, second, and third laminae. Special care should be taken in dealing with the arch of the atlas, because of the presence of the large vertebral veins at either end of it. The best way to manage this is to make a transverse incision in the periosteum with the cutting current at the inferior edge of the bone, and cautiously shell out the arch little by little.

Next, the dura is cleaned of the epidural plexus of veins, which are picked up one by one and coagulated. The dura itself is incised longitudinally. The incision to be used for root section for torticollis will be described below, under that heading. If merely a chordotomy is to be done, the dura should be opened as far to the side as will permit an easy closure—usually over the posterior roots. The dura is retracted with sutures, and oozing from its edges carefully dried with light touches of a cutting current. When the toilet of the wound is complete, and its raw edges covered with flat cotton wadding, the arachnoid is finally torn open.

The anterolateral surface of the cord

is exposed by picking up the dentate ligament between the fourth and fifth segments in a mosquito snap, and severing its attachments lateral to the snap. The cord can then be gently rotated posteriorly, bringing the anterior roots into view. Particular care should be taken—as in all operations on the spinal cord—to avoid injury to posterior roots, which may result in girdle pains after operation.

There is a choice between several meth-
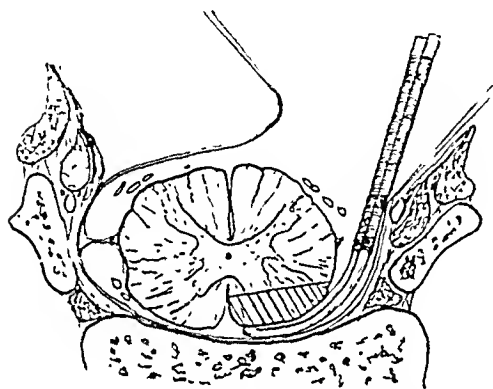


FIG. 160. Diagram of operation of cauterization of anterior columns of spinal cord. Cautery should be just hot enough not to stick to tissues.

ods of destroying the anterior column. The older method is to make a small longitudinal incision in the line of the anterior roots. (If a small blood vessel stands in the way, it may be picked up on a dural hook, which is then touched with the cutting current.) The longitudinal incision permits the easy entrance of the smallest-bellied Bard-Parker knife (No. 15), which is thrust inward to a depth of about 5 mm., then pressed forward to emerge through the pia. This entails considerable danger of bleeding from the anterior spinal artery. If bleeding occurs it may be arrested by placing a piece of muscle anterior to the cord, and pressing the pia against it by means of a blunt hook inserted into the incision.

A preferable method is the use of the "cold" cautery (Dusser de Barenne[28]). A small pointed nasal cautery (Seiler's type M), heated by two dry cells in series, rises to a maximum temperature of about 80°, at which temperature it does not stick to tissue. If it is pressed against the anterior surface of the cord for about 30 seconds, nervous structures are destroyed to a depth of about 2 to 3 mm. (Figs. 160, 161). The respiratory tracts, running within the extremely vascular gray matter, are relatively safe, as are large vessels. As assurance, cauterization can be carried out several times at slightly different locations.

Whichever method is used, the region between the anterior roots and the frontal meridian of the cord should be avoided, as it contains the spinothalamic tract.

At this point in the operation or before, a transfusion should be given routinely. Ether should be discontinued, and all preparations made for administration of a carbon-dioxide mixture if the respiration is embarrassed.

There is usually little bleeding from the chordotomy. As soon as the surface of the cord is dry the dura is sutured, then the muscles of the neck in many layers with interrupted silk stitches. No stronger reinforcement is necessary, and no drainage is used. A "liquid adhesive" dressing is applied over a small strip of boric-ointment gauze, then a small laparotomy pad over that, and a padded cardboard collar outside. This support need be maintained only as long as it gives the patient comfort.

The most important point in after-care is a careful watch for evidences of respiratory embarrassment, such as the slightest cyanosis or the development of the "progressive confusional syndrome."[29] The latter is a condition in which, as a result of anoxia of the brain, the patient loses his memory for recent events, so that he has difficulty in remembering that he has been operated upon, or who has been to see him.

Later he becomes disoriented, delirious, negativistic, and abusive. The condition is aggravated by the use of sedatives. The remedy is the use of a Drinker respirator.

section of the anterior column, lasting from a few days to a few weeks. As voluntary power returns, some of the old abnormal movements also make their ap-



Fig. 161. Section of cervical cord, from a patient who died five months after cauterization of anterior column, to show descending degeneration produced (arrows). Weigert stain.

Administration of oxygen or of carbon dioxide is rarely of benefit, for the fault is with neither the pulmonary epithelium nor the respiratory center

Paralysis of the bladder should also be

pearance, but seldom to more than a small extent if the chordotomy is sufficiently radical (Figs. 154, 155, 162). In several cases re-operation has appeared advisable because of the return of symptoms, and the
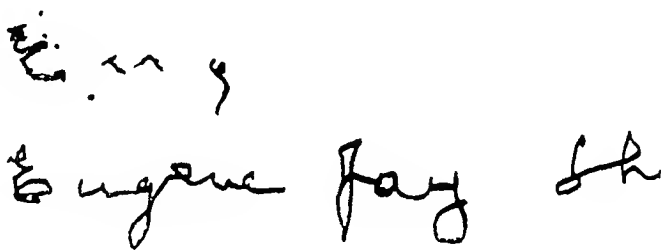


Fig. 162. Handwriting of patient suffering from athetosis before (*above*) and after (*below*) cauterization of anterior columns.

watched for. If the patient has to be catheterized more than twice, it is usually wise to install a tidal-irrigation apparatus to forestall infection. Control is always eventually regained.

A flaccid paralysis usually occurs after

results after the second operation have been among the most satisfactory in the series.

In bilateral cases, the procedure may be repeated one segment lower after a lapse of six months or more

## SPASMODIC TORTICOLLIS

Slow, rhythmic spasms of the neck often form a part of the syndrome of generalized athetosis or dystonia. The same symptom may exist as an isolated fragment, usually with a few mild dystonic manifestations elsewhere (Fig. 163). The movements have the characteristics of athetoid movements of other parts of the body, as is brought out clearly by electromyography. In typical cases (reviewed by Alpers and Drayer[30]), lesions have been found in the nervous system. The etiology is obscure, but presumably the same as that of other types of athetosis. The disease is usually slowly progressive to a fixed state. In some cases, however, spontaneous remissions occur—a circumstance extremely rare in other varieties of the athetoid syndrome.

There exist in addition other types of "forced" movement of the neck, some of them doubtless hysterical in origin. The latter respond to psychotherapy of various kinds.[31] Unfortunately, clinical differentiation between the two groups is difficult. An apparent distinction may be made by the use of a partial anesthesia with hyoscine, evipal, or pentothal. The hysterical patient in a drowsy state usually will give up his symptom; the dystonic usually will not. Electromyography is useful in differential diagnosis.

Relief of dystonic torticollis by means of psychotherapy has been reported.[32] Cures have also been observed following the administration of curare,[11] and after infiltration of the muscles with procaine,[33] all in isolated instances. It is obviously difficult to evaluate such reports. In the author's personal experience, the use of curare or procaine infiltration is not of permanent value, and most cases which come to operation have been treated conservatively for years without relief. Orthopedic treatment appears to have been abandoned. A wise policy would seem to be to recommend the patient to any reputable psychiatrist or orthopedist in the community who is will-



Fig. 163. Successive positions of head in a case of spasmodic torticollis. From a moving picture. Frames approximately one second apart.

ing to hold out even a slight hope of relief, merely laying the facts before him. As with operations for pain, it is better to wait until the patient demands to have something done rather than to urge an operation on him. It may fairly be said that the modern operation will remove most of the abnormal movements and permit the head to be held relatively still, without loss of the ability to turn the head. An atrophy of the neck muscles is to be expected, but it is less disfiguring than the hypertrophy caused by the disease. The sternomastoids will be reduced to remnants, and there may be a certain degree of shoulder drop. Other dystonic symptoms (for example, scoliosis or tremor of the hand) will not be affected unless a chordotomy is done at the same time. Warned of all these disadvantages, patients are usually anxious to have the operation performed, and grateful afterward. The widespread pessimism as to the permanence of the results is a relic of the days of tenotomies, operations on the sensory roots, and other procedures which are obsolete.

Operative Treatment of Torticollis. The procedure to be described is slightly modified from that reported by Foerster[34] and by Dandy.[37] A valuable case has also been reported by Dowman.[36] The object of the operation is to cut the first three cervical anterior roots within the dura, and the spinal accessory either in the posterior fossa (Foerster) or in the neck (Dandy). The operation may be combined with section or cauterization of one anterior column for relief of athetosis or dystonia, as described above

The preparations for operation, and the laminectomy of the first three vertebrae, are carried out exactly as described for anterior chordotomy, with the exception that removal of laminae has to be extremely radical, exposing the articulations of all except the first vertebra (where they are covered by the vertebral veins). No attempt should be made to enlarge the foramen magnum.

The dura should be opened in the midline up to the arch of the atlas. From this point, the incision should diverge to make a V-shaped opening, as the sinus often extends below the bone and may give rise to annoying bleeding. The incision should not be carried quite to the edge of the bone to avoid the branches of the sinus there. If a chordotomy is to be performed on one side (never on both at once), a transverse incision may be made at the appropriate level. Any bleeding points on the edge of the dura should be lightly coagulated.

After the dura has been retracted with sutures over sheets of absorbent cotton wadding, attention may be turned to the anterior roots. Those most difficult to secure are those of the first segment. There are no posterior roots to call attention to them, and they are usually hidden under a dense slip of arachnoid. They are adjacent to the vertebral arteries (Fig. 165). For these reasons a special search should be made for them before anything else is done. They may be destroyed by pinching with a small, perfect hemostat then cut, if feasible.

Next, the second and third anterior roots may be attacked. It is unnecessary to cut posterior roots, though the sacrifice of a few filaments is of no consequence. The posterior roots may be lifted aside with a blunt hook, and the anterior filaments crushed with a hemostat. It is as well to work first above, then below each group of filaments.

At this point the chordotomy should be done if it is indicated.

Finally, the question of the spinal accessories should be considered. In some instances most of the rootlets are easily reached in the posterior fossa, in which case they should be crushed there (with care to avoid the hypoglossal). If they are difficult to reach, however, or if the pa-

tient's condition gives the slightest concern, it is wiser to close at once, and plan to cut the nerve in the neck, where it crosses under the sternomastoid, either at the same session, or a week or two later.

In occasional cases it is wise to cut the spinal accessory on one side or the other as a first step, in the hopes that an intradural operation will not be necessary.

Cases occur, on the other hand, in which



FIG. 164. Same patient as shown in Fig. 163 after section of first three anterior cervical roots and spinal accessories bilaterally.

the spasms are not relieved by section of only three anterior roots. Under these circumstances the fourth roots may be cut at another operation. It is wiser not to take them at the first session, because of danger to the phrenic.

Recent experience has shown that section of the roots of the spinal accessory in the posterior fossa, plus section of the trunk in the neck as it crosses the sternomastoid, may not control the contractions of the group of muscles it innervates. Further,

spasms of the deep musculature may persist after bilateral section of the first three anterior roots and the accessories. Under these circumstances, additional relief may often be obtained by a modification of the Finney operation,—section of the posterior divisions of the spinal nerves from $C_4$ to $C_7$ inclusive. This operation is carried out through a midline incision, as far as the deep fascia. It then follows the fascial plane between the trapezius and the splenius. The posterior divisions, which are inconspicuous, leave the foramina in company with an artery and a vein, and curve backwards over the ends of the transverse processes. They are picked up, identified by stimulation, and evulsed.

The dressing and support for the neck are as described above under anterior chordotomy. Owing to weakness of the neck the padded collar must be worn for several weeks. The patient is often apprehensive that he will not be able to support his head, but he may be given absolute assurance on this point (Fig. 164).

## ALTERNATING TREMOR AND PARALYSIS AGITANS

Although the parkinsonian syndrome and the related varieties of resting, alternating tremor have long been recognized as distressing and crippling diseases, attempts at surgical treatment have been made only in recent years. The reason for such a late start has undoubtedly been a lack of understanding of the physiologic basis of the syndrome. The opportunity offered by many cases must have been obvious to all who have considered the problem. Patients afflicted with tremor and rigidity may at times throw off their symptoms, and appear as well, agile, and strong as ever in their lives. The transformation may be brought about by emotional stress, or by the use of certain chemical measures (atropine derivatives in certain cases; injection of curare). It seems not too much

to hope that such a dramatic improvement might be made permanent.

Far-reaching distinctions between the caused by a regular, rhythmic contraction alternately of extensors and flexors (Fig. 166). The character of the movement is
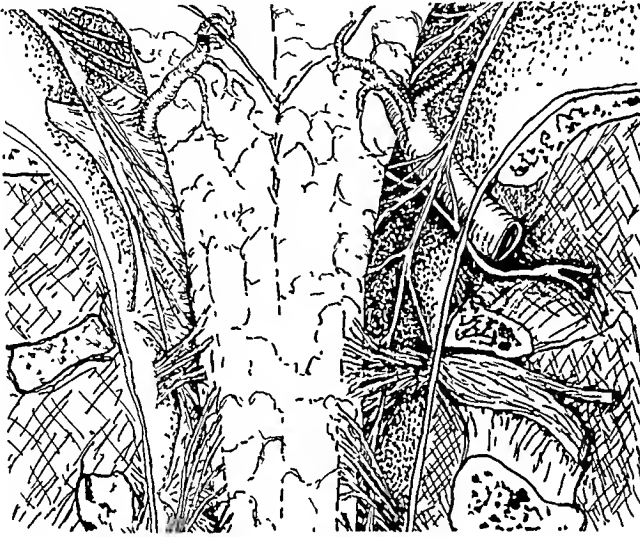


FIG. 165. Dissection of upper cervical cord and medulla, seen from behind. On left, upper portion of dentate ligament is seen; on right, it has been removed to show first cervical nerve in relation to vertebral artery.
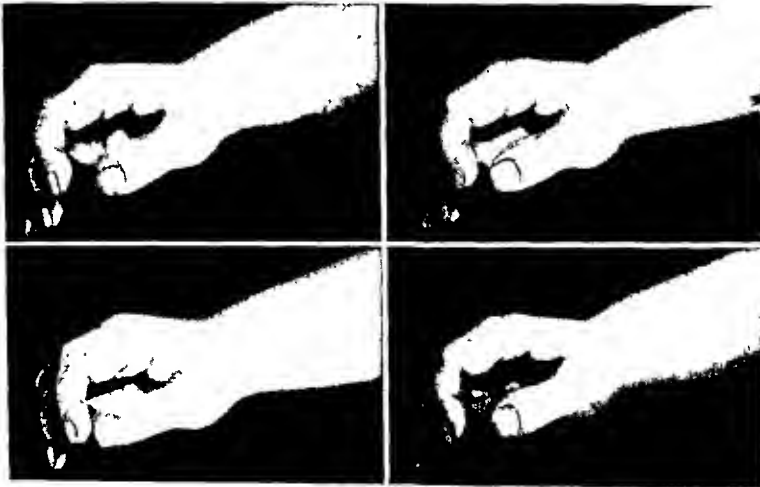


FIG. 166. Successive positions of fingers in a case of alternating tremor. Enlarged from a moving-picture film; frames taken about $\frac{1}{10}$ second apart. Note stereotyped pattern of movement.

syndrome of athetosis and that of alternating tremor can be recognized. Clinically, tremors of rest may be observed to be most clearly brought out by electromyography. From records of the muscle action currents, it may be seen that the contrac-

tions occur as isolated bursts of activity which are simultaneous in many motor units throughout the muscle (Fig. 167) (unlike voluntary contraction, in which the motor units discharge asynchronously[3]). In contrast to the simultaneous irregular contraction of many or all muscles of the affected region in cases of athetosis, producing a slow, squirming movement at the expense of a large output of work and massive increase in oxygen consumption, there is a relaxation of antagonists in cases of alternating tremor, permitting the characteristic quick movement with little expen-

day until symptoms of overdosage occur. A higher level may often be maintained if the patient is given pilocarpine in doses of about ⅛ gr. (0.2 Gm.) t.i.d. by mouth. If blurring of vision is troublesome, stronger glasses or bifocal lenses may be employed. Dryness of the mouth may be mitigated by chewing gum. Amphetamine (benzedrine) sulfate is often a useful adjuvant, in doses of 10 to 40 mg. daily. Exercises in relaxation and retraining are sometimes a moral support, but have not been advocated as enthusiastically as they have in the treatment of athetosis.
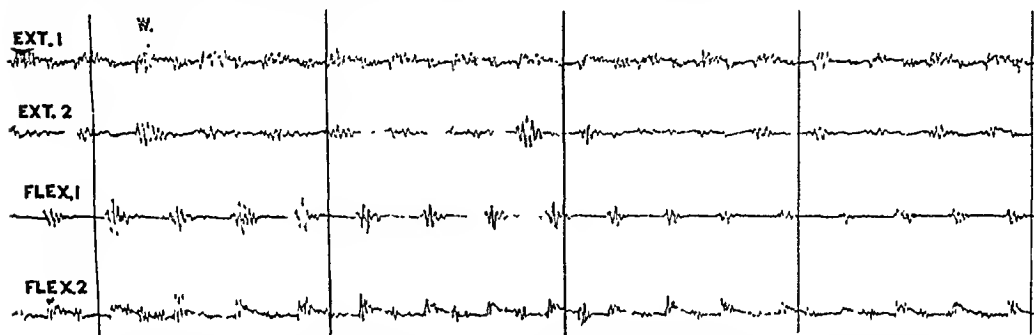


FIG. 167. Electromyograms from a case of paralysis agitans (needle electrodes). Note that all portions of contracting muscle discharge practically simultaneously, while antagonist relaxes. (Courtesy, Dr. Paul Hoefer.)

diture of energy. These distinctions are of practical importance in planning a program of treatment in a given case.

Nonoperative Treatment of Alternating Tremor. This subject, rightfully considered fully in textbooks of medicine and neurology, will receive only brief mention in this volume.

The most generally successful treatment is the use of drugs of the hyoscine series. Pills of stramonium leaves (2½ gr., 0.15 Gm.) given by mouth in increasing doses beginning with two a day, pushed to the point of tolerance, are convenient. The newly introduced wine of Bulgarian belladonna occasionally seems slightly more effective. It is prescribed in doses of three drops t.i.d., slowly increased by a drop a

Surgical Treatment of Alternating Tremor. Methods of operative treatment of paralysis agitans are comparatively new and unstandardized, and any statements made concerning them must be considered as provisional.

The most suitable cases for treatment are those in relatively young individuals in which one extremity or arm and leg on the same side are rendered useless by involuntary movements. Under such circumstances the affected extremity is usually not only no asset, but constitutes an actual liability to the unfortunate patient, who often occupies the better hand in restricting the tremulous one, and feels conspicuous in public and exasperated when alone by the ceaseless unrest. Where the

usefulness of the extremity is merely impaired, some types of operation may increase it, others decrease it. Klemme[19] has operated on bilateral cases, and on patients in the early senium. It should go without saying that medical treatment should be given a thorough trial, and that the patient's general condition and social and economic situation must be considered.

logical Unit of Boston City Hospital, the tremor was relieved by removing area 6 alone, or with a small strip of area 4; that is, an electrically excitable area at the summit of the precentral convolution (Fig. 168). As there is little agreement concerning the location and extent of the cortex which must be removed in order to secure a favorable result, the procedure suggested
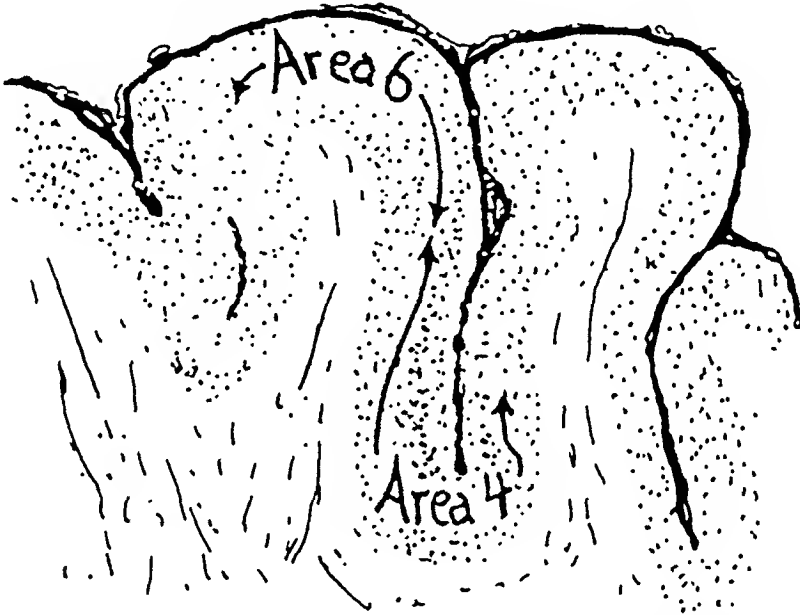


Fig. 168. Drawing from a section through motor cortex, in region of "arm" area, showing relative locations of Area 6 and Area 4. Notice that latter lies almost completely hidden in depths of sulcus.

wholly successful. The longest series (that of Klemme[19]) has not yet been described in detail. In some at least of Klemme's cases, the additional weakness and disability produced by the operation appears to have been slight. In the instance of Bucy and Case[37] it was marked, since the entire motor representation of the hand was sacrificed. It has been moderate in the cases observed at the Neurological Unit, but on the whole greater than that produced by pyramidotomy (see p. 296). Cortical operations have the advantage that they can be used for the relief of tremor confined to one hand, and for tremor of at least the left side of the face and neck.
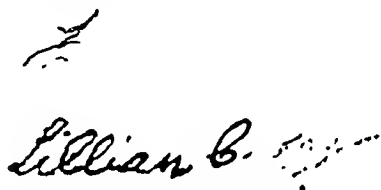


FIG. 169. Handwriting of a patient relieved of severe alternating tremor by complete section of lateral pyramidal tract. Patient had been unable to write for 16 years prior to operation.

There should be little choice in safety between operations on the cortex and section of the pyramidal tract, which is far simpler than section of the anterior column. Klemme[39] has reported a mortality of 17% from cortical operations for tremor, while none has been ascribed to pyramidotomy. The possibility that convulsions may be incited by a cortical operation must be considered. Which type of operation is better adapted to bilateral cases remains to be seen.

An alternative to cortical extirpation in the treatment of alternating tremor is section of the lateral pyramidal tract in the cervical region. This operation has been carried out in thirty-four instances. The tremor was almost completely relieved in the affected arm and leg in most cases. The patients (with one exception) were able to walk better than before the operation, and in all instances the usefulness of the affected hand was improved so that (in right-sided cases) they were able to write (Fig. 169), handle a glass of water (Fig. 170),



FIG. 170. Patient drinking from a glass of water, after complete section of lateral pyramidal tract in cervical spinal cord.

make individual finger movements, and use the hand in dressing.

Section of the lateral pyramidal tract apparently disturbs the function of the hand less than any of the operations upon the electrically excitable cortex. For this reason it might be preferred for patients suffering from tremor of the right hand. If there is tremor of the left hand alone, a cortical operation might be preferable, in

order to avoid impairing control of the leg. If the leg alone or both arm and leg are involved, pyramidotomy is probably easier and more conservative than the corresponding cortical operation. If it eventually turns out, however, that cortical extirpations which spare the primary motor cortex are regularly successful in relieving tremor, section of the pyramids should probably be abandoned. The author's own experience makes this seem unlikely.

from large pial vessels. If no open space is available a vessel may be picked up on a fine hook and coagulated. On the blade of a small, sharp-pointed Bard-Parker knife (No. 11) the depth of 4 mm. from the point is marked by a scratch or with a rubber band. The point of the knife is inserted just lateral to the line of emergence of the posterior roots, with the edge pointed outward. It is inserted at an angle of about 10° from the vertical, toward the center of the cord, to the depth of 4 mm. marked,
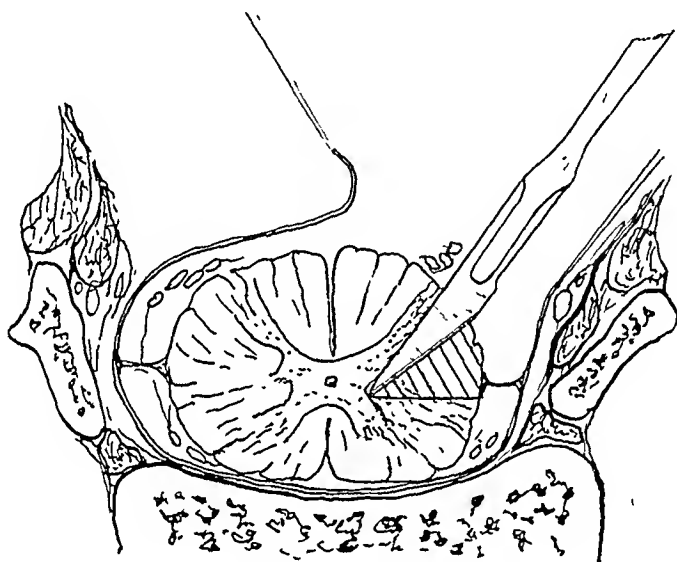


FIG. 171. Diagram of operation of section of lateral pyramidal tract.

Section of the lateral pyramidal tract is performed as follows: The anesthesia, preparation, and laminectomy are carried out exactly as described on p. 296 for section of the anterior column. The lamina of the second cervical vertebra should be removed on the side of the proposed incision, but less room need be provided than for an anterior chordotomy. The dura is opened slightly lateral to the origin of the posterior roots, and is retracted with sutures over absorbent cotton wadding.

A region is chosen in the second cervical segment where the lateral column is free

and then swept lateral so that the point emerges at the horizontal meridian of the cord, marked by the dentate ligament (Figs. 171, 172). It is well to insert the tip of an ordinary scalpel in the wound thus made, and ask an unprejudiced bystander to measure the extent of the incision, as the question is sure to arise afterward.

If there is any oozing from the incision so made, it is controlled by light pressure with a cotton pledget. When the wound is dry the dura is sutured and the wound in the neck is carefully sutured in layers with silk. The dressing and support for the neck

are precisely as described for the operation for athetosis.

No particular postoperative care is required. If there is any trace of tremor on the side operated upon (or elsewhere in the body), the usual medical treatment may be given, and is ordinarily more effective, in smaller doses than before Interestingly enough, the patient's tolerance is also decreased.

Still a third method of treatment of uni-

cortical operations may be carried out, but this would appear to involve increased danger to the function of both hands. A pyramidotomy may be combined with a homolateral cortical extirpation, or bilateral section of the pyramidal tract may be performed, apparently without increased disability. A period of several months should usually be allowed to elapse between the two operations

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Fig. 172. Section of cervical cord, from a patient who died of pyloric obstruction six weeks after section of lateral pyramidal tract (arrows) for alternating tremor. Marchi stain.

lateral tremor is partial removal of the head of the (contralateral) caudate nucleus (Meyers[14]). The frontal cortex is exposed, the motor strip identified, and the ventricle is opened well anterior to it. The caudate nucleus is recognized as a swelling in the floor of the ventricle, and its head excised or sucked out. Details should be read in the original article. From the author's own experience, it seems likely that the benefit obtained is due to damage to the pyramidal tract.

Bilateral tremor may be treated by a two-stage combination of operations. Two

of the basal ganglia was held by the Association for Research in Nervous and Mental Diseases in December, 1940. The volume containing the Proceedings of the meeting[39] contains a group of papers covering many aspects of the subject, including further reports on the surgical procedures carried out by both Klemme and Meyers.

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# 16

# Epilepsy Due to Atrophic Cerebral Lesions

## Theodore C. Erickson, M.D.

One who ventures to undertake the surgical treatment of epilepsy must be prepared to deal with a wide variety of intracranial pathologic conditions.

Epilepsy, a symptom, is the specific reaction-form of different portions of the brain to irritative foci. It depends also for its development upon the existence of certain inherited and acquired susceptibilities of the patient as well as the occurrence of other physiologic changes which precipitate the epileptic seizures. These latter predisposing and precipitating factors have been discussed in a publication by Penfield and Erickson[1].

Although more than 60 "causes" of epilepsy have been recorded, patients with epilepsy may, for our purpose, be placed in two general groups: (1) those with and (2) those without demonstrable cerebral lesions.

In Group B of the following table, those without demonstrable cerebral lesions, are the patients best treated medically. In Group A, those patients with epileptic seizures due to cerebral neoplasm and abscess, are some of the major problems of neurosurgery, which have been dealt with in previous chapters.

This chapter is concerned with the clinical investigation of patients with epileptiform seizures and with the surgical

### An Etiological Classification of the Epilepsies
#### (From Penfield and Erickson[1])

A. *With Demonstrable Cerebral Lesions*

|  | | Produced by |
|---|---|---|
| | 1. Expanding lesions | Neoplasm, abscess, etc. |
| Atrophic Cerebral Lesions | 2. Cerebral cicatrix | Trauma, infection |
| | 3. Local cerebral atrophy | Compression, ischemia, infection |
| | 4. Local microgyria | Infantile compression or ischemia |
| | 5. Brain cyst | Vessel closure or hemorrhage |
| | 6. Diffuse cerebral disease | Degeneration, infection, sclerosis |
| | 7. Diffuse cerebral vascular disease | Arteriosclerosis, syphilis |
| | 8. Miscellaneous | Congenital lesions, etc. |

B. *Without Demonstrable Cerebral Lesions*

|  | Produced by |
|---|---|
| 1. Cryptogenic (idiopathic) | Abnormal cerebral physiology |
| 2. Toxic and febrile | Extracerebral causes |
| 3. Hypoglycemic | Extracerebral causes |
| 4. Miscellaneous (angioneurotic, circulatory arrest, etc.) | |

treatment of atrophic cerebral lesions (see the table on page 310) which serve as epileptogenic foci. The author is indebted through long continued and close association to Dr. Wilder Penfield whose studies in this field are pre-eminent.

As one is faced with the epileptic patient in practice, it is not always possible to make an etiologic diagnosis without an exhaustive investigation. A presumptive diagnosis may often be made, however, by a consideration of the most common causes of epilepsy in different age groups as presented in the outline in the following table. Such a presumptive diagnosis is of great help in directing further clinical inquiry.

full description of the seizure and of any post-ictal paralysis should be recorded. It was pointed out by Hughlings Jackson that epilepsy is an excessive local neuronal discharge which spreads by contiguity to adjoining areas of the cortex. When this site of origin is subcortical, the entire cerebral cortex may be involved simultaneously and so appear as a generalized process from the onset. However, when the character of the seizures and their onset is known, one can usually localize the site of the epileptogenic lesion from a knowledge of cerebral localization (Fig. 173).

Turning of the head and eyes to the opposite side (adversive seizure) is one of the

PRESUMPTIVE DIFFERENTIAL DIAGNOSIS BASED UPON AGE OF ONSET

| Age of Onset | | Presumptive Cause |
|---|---|---|
| Infancy | 0– 2 | Birth trauma, tetany, febrile illness |
| | | Congenital or degenerative disease |
| Childhood | 2–10 | Birth injury, febrile cerebral thrombosis |
| | | Cerebral trauma, cryptogenic |
| Adolescence | 10–20 | Cryptogenic, cerebral trauma |
| Youth | 20–35 | Trauma, neoplasm, cryptogenic |
| Middle Age | 35–55 | Neoplasm, trauma, arteriosclerosis |
| Senescence | 55–70 | Arteriosclerosis, neoplasm |

Careful and thorough study of all epileptic patients is a necessary prerequisite to surgical treatment. The methods of studying these patients may be divided into clinical, radiographic, and electrographic.

## CLINICAL ANALYSIS

History. In taking the history of the patient with epilepsy there are several points of prime importance when it comes to making a decision whether surgical treatment is indicated.

Do the seizures have a focal onset indicating a focal cerebral lesion? Description of the seizures should be obtained not only from the patient, but also from friends or relatives who have observed the attacks. Inquiry as to the aura or the onset of the attack should be specific and detailed. A

most common modes of onset of an epileptic seizure and usually indicates an epileptogenic lesion in the premotor area. The fact that a lesion irritating the precentral gyrus produces a typical Jacksonian march is well known. Attacks which begin with numbness or tingling of the arm or leg indicate a lesion of the postcentral gyrus and those which begin with dizziness or with a buzzing indicate a lesion of the temporal lobe. A lesion low in the temporal region so as to affect the uncinate gyrus produces an olfactory hallucination, usually an unpleasant odor. A further discussion of the localization problem is outside the scope of this chapter, but the most important facts are presented in Fig. 173 and also in the table immediately following. For a more complete discussion of the subject of cere-

Epileptic Seizures: Clinical and Anatomic Classification
(Modified from Penfield and Erickson[1])

| *Clinical Type* | *Localization* |
|---|---|

**Motor**
1. Generalized seizure (Grand mal) .....................Motor & associated systems
2. Jacksonian seizure (Focal motor, partial)..............Pre-Rolandic gyrus
3. Masticatory (Smacking, salivation, swallowing) .......Lower Rolandic gyri
4. Simple adversive seizure ...........................Frontal, premotor
5. Tonic seizure ("Cerebellar," decerebrate) ............Brain stem

**Sensory (Auras)**
6. Somatosensory seizure ...........................Post-Rolandic gyrus
7. Visual seizure (Lights, darkness) ....................Occipital & postparietal
8. Auditory seizure (Buzzing) ........................Temporal
9. Vertiginous seizure (Dizzy spell) ....................Temporal
10. Olfactory seizure (Uncinate) ... ....... ............Infra-temporal

**Visceral**
11. Autonomic seizure (Vasovagal) .....................Diencephalic

**Psychical**
12. Petit mal seizure (Lapse, absence, pyknolepsy)
13. Psychomotor seizure (Confusion, coordinated misbehavior)
14. Automatism, postepileptic confusion
15. Dreamy state (Déjà vu, unreality, near, remote); Temporal
16. Psychotic states (Secondary)
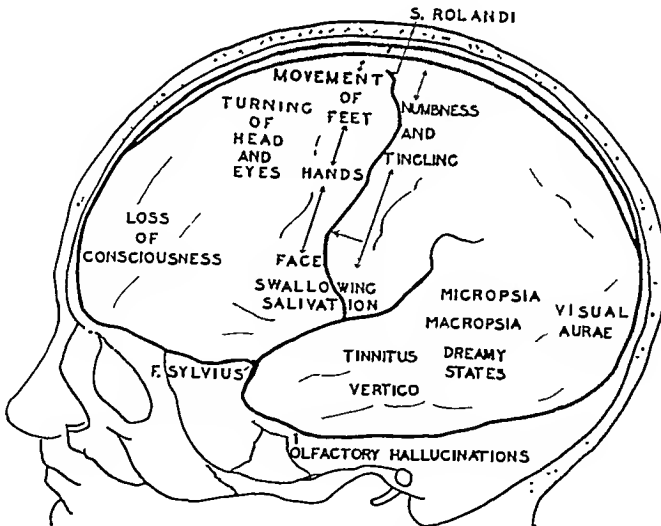


Fig. 173. Cerebral localization as indicated by onset of epileptic seizures.

bral localizations, the reader should refer to any good textbook of neurology or to Penfield and Erickson.[1]

The next question to be asked of the epileptic patient concerns a possible cause for focal pathologic change in the brain. Does the patient have a history of head injury, difficult or prolonged birth, old brain abscess, meningitis, or cerebral venous thrombosis which may have been responsi-

ble for the development of a focal contracting cerebral lesion? The past history must be carefully elicited from both the patient and his relatives.

Physical Examination. Examination of the patient may provide evidence of the presence of a focal contracting cerebral lesion. There may be an old scalp scar or defect in the bone to indicate the site of a meningocerebral cicatrix following a severe head injury. Asymmetry of the skull may be evident either on clinical examination or on x-ray films, and if so it indicates the presence of an atrophic lesion dating from childhood. Bodily asymmetry may also result from a destruction of portions of the parietal lobe and as such is a valuable localizing sign. The symmetry of the two sides of the body must be carefully examined by measuring the distance of the nipples from the midline of the body and by comparing the size of the hands, arms, and legs on the two sides. Any bodily asymmetry may be evidence of a destructive lesion in the postcentral region.

Neurologic Examination. The results of neurologic examination are of prime importance for they may provide a clue as to the location of a focal lesion when no other is present. On the other hand the neurologic examination may reveal no abnormality even in the presence of a large epileptogenic cicatrix. Reflex changes or paralysis may be present for a few minutes, hours, or even days after severe epileptic seizure. Such post-ictal paralysis may furnish localizing evidence when other evidence is lacking.

When no adequate description of the attacks is available, it is advisable to have the patient admitted to a hospital where the attacks can be objectively observed and described by trained nurses and house officers. The first step is to discontinue all anticonvulsant medication. Not infrequently patients who have been receiving phenobarbital go into status epilepticus

when their medication is suddenly discontinued, and for this reason they should be carefully watched and put back on medication as soon as a seizure has been adequately described. If no seizure occurs with cessation of medication, some method must be employed to precipitate the attacks. The simplest of these is the *hyperventilation test* which is, however, effective in only 10 to 15 per cent. The patient is made to breathe as deeply and as rapidly as possible for a period of ten minutes. When there is good cooperation, carpopedal spasm and a positive Chvostek sign appear in two to three minutes and in susceptible patients a typical seizure follows. Oftentimes the seizure occurs just after the overbreathing is discontinued, so observation should be continued a half hour or more. The seizure, when it occurs, is of the same pattern as the patient's usual attack.

The most reliable and useful means of precipitating an attack is a *hydration régime* such as the following:

1. Water by mouth, 3 to 5 cc. per kg. of body weight per hour. (This may be flavored with lemon juice and sugar.)

2. Weigh patient every six hours after he has voided. (Expect from 2 to 6 per cent gain in weight.)

3. Measure and chart patient's intake and output.

4. Pitressin intramuscularly, 0.5 cc. increasing gradually to 1.5 cc. every three hours.

5. Observe and record carefully all symptoms such as headache, nausea, vomiting, dizziness, drowsiness, and malaise, as well as convulsions.

6. Discontinue this régime as soon as two convulsions have been observed from the onset and accurately described.

7. Immediately recommence anticonvulsant medication such as phenobarbital, so as to prevent the patient from going into status epilepticus.

When focal epileptiform seizures have

been accurately seen or described, it is desirable to proceed with radiologic and electro-encephalographic studies. To save time, they may better be carried out simultaneously.

## RADIOLOGIC STUDY

Stereoscopic lateral and anteroposterior x-rays of the skull should be taken of all epileptic patients. The presence of an old depressed skull fracture or fracture lines may indicate the site of a meningocerebral cicatrix. Skull defects as the result of old head injuries or of the drainage of healed brain abscesses may be disclosed. "Stalactite" formation from the internal surface of the skull may occur if there has been a defect in the dura. An asymmetry of the two sides of the skull may indicate the presence of an atrophic cerebral lesion on the smaller side, dating from early childhood. Such are some of the common findings in the presence of epilepsy due to an atrophic cerebral lesion. Clinically, the dividing line between expanding and contracting or atrophic cerebral lesions as the cause of seizures may not be evident on preliminary examination; and skull x-ray may disclose evidence of a slowly growing neoplasm as the cause of the seizures. However, a normal skull x-ray does not rule out the presence of a cerebral cicatrix.

Pneumo-encephalography. This is one of the most valuable diagnostic procedures in reaching a decision as to the advisability of operative intervention in a patient with epilepsy. This subject has been considered in a previous chapter.

Local dilatation or tenting of the outlines of the ventricles, displacement of the septum pellucidum toward the side of the lesion, and abnormal collections of gas or uneven filling of the subarachnoid space are the most important indications for operation. These radiographic signs should be evaluated in the light of the localization of the epileptogenic lesion made from neurologic examination and study of the patient's seizures. Valuable confirmation may be furnished by the electro-encephalogram.

Electro-encephalography. Electro-encephalography of the epileptic patient gives evidence which, when combined with the results of clinical and pneumo-encephalographic studies, enables one to make a proper choice of the epileptic patients who are suitable for operative treatment. Surgical excision of an area of the brain solely because it is the site of an electro-encephalographic "epileptic" focus has not proved successful in stopping epileptiform seizures however. But if the electro-encephalographic focus corresponds with the clinical and radiologic localization, there is good reason for surgical intervention. Electro-encephalography is especially valuable as a preliminary test in the office or dispensary to decide whether further study of the patient in the hospital is advisable. Good reviews of the clinical applications of electro-encephalography may be found in the monograph by Gibbs and Gibbs[2] and in the chapter by Jasper in Penfield and Erickson.[1]

## INDICATIONS FOR OPERATION

In focal epilepsy the decision as to whether operation should be undertaken depends then upon the presence of positive evidences of a focal cerebral lesion as judged by the clinical evidence and confirmed by the findings on pneumo-encephalography and electro-encephalography. Operation should not be undertaken unless the evidence from at least two and preferably all three sources agrees closely.

## CONTRAINDICATIONS FOR OPERATION

The contraindications are: (1) The absence of objective evidence of a focal lesion, and (2) the presence of diffuse or multiple lesions. In nonfocal epilepsy surgical therapy has little justification unless

there is evidence of increased intracranial pressure such as occurs, for example, with craniostenosis. In the latter event subtemporal decompression may be indicated for this as well as other symptoms. Decompressive operations are of no value in the treatment of epilepsy unless there is specific evidence of increased intracranial pressure. The presence of multiple lesions is not an absolute contraindication, for in a few instances multiple but discrete cere-

1. **Preoperative Orders and Preparation.** The hair may be clipped the evening before, but it is best not to shave the head until the morning of operation. Inspection of the scalp should be carried out after it has been shaved to make certain that there is no existing skin infection that may increase the risk of postoperative infection. It is well to give a cleaning enema before operation so that avertin anesthesia can be given by rectum if desired after completion
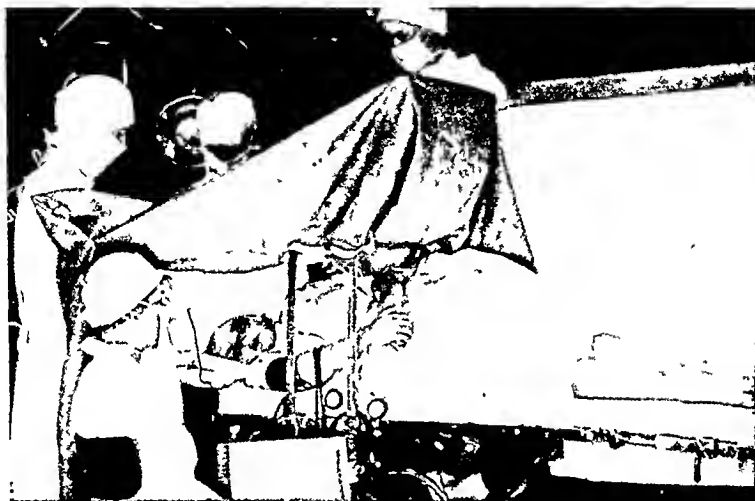


Fig. 174. Method of draping to permit observation of epileptic seizures during operation.

bral cicatrices have been removed with subsequent cure of the epilepsy. In most cases, however, multiple cicatrices cannot be removed with benefit to the patient. Although the presence of marked mental deterioration does not augur well for the result following operation, lesser degrees of personality change may be improved.

## OPERATIVE TECHNIC

The general principles and technic of intracranial surgery have been discussed elsewhere. There is need to consider only the special problems arising in the craniotomy for removal of atrophic cerebral lesions causing epilepsy.

of cortical stimulation. A glass or two of sweetened fruit juice three or four hours before operation will help to minimize the effects of fluid loss and starvation during operation.

Codeine (usually in the form of codeine sulfate gr. i) has been found to be the most suitable preoperative sedative in that it has little effect in reducing cortical excitability. Other sedatives may make the patient too drowsy to respond correctly to cortical stimulation.

2. **Operating-room Set-up.** This is similar to that for any craniotomy under local anesthesia. To facilitate electrical stimulation of the cortex attention should be di-

rected at the draping of the patient so that he or she can be easily seen by a trained observer or anesthetist. Fig. 174 shows a satisfactory method of draping to accomplish this purpose.

satisfactory for the skin and aponeurosis, while a 1 in 4,000 solution may be used beneath the aponeurosis. The addition of adrenalin (0.2 cc. per 100 cc.) decreases hemorrhage from the scalp flap.



Fig. 175. Osteoplastic bone flap turned back to show dural defect and corresponding change in skull following old head injury.

3. Anesthesia. Local anesthesia is the anesthetic of choice for it permits of electrical stimulation of the cerebral cortex, accurate cerebral localization, and identification of the focus of epileptic discharge by physiologic methods. For this purpose a 1 in 1,500 solution of nupercaine is very

In practice the following procedure is convenient: (1) In succession sterilize the skin with green soap, alcohol, ether, and iodine 7 per cent, (2) After three minutes remove all iodine from the head with alcohol. The scalp flap is then carefully outlined with a hemostat dipped in tincture of

iodine. (3) The local anesthetic (1 in 1,500 nupercaine solution) is injected subcutaneously along the course of the projected incision and added amounts are injected deep in the temporal muscle. A weaker solution (1 in 4,000 nupercaine solution) is then injected beneath the aponeurosis by inserting the needle vertically until it strikes the bone and injecting solution until a ridge 1 cm. high is raised. When this is completed, the skin flap is defined with a light stroke of the scalpel. The drapes are sutured to the scalp and the draping and instrument set-up is completed.

4. **Reflection of Osteoplastic Flap.** The technic of reflecting the osteoplastic flap in the presence of a cerebral or meningo-cerebral cicatrix does not differ except in details from that in the patient with a brain tumor. With a meningocerebral cicatrix which is prone to be attached to the skull, certain precautions are necessary. The x-rays of the skull should be carefully examined for the presence of old fracture lines, stalactite formation, or bone defects. The dura may be firmly adherent to an old fracture line in the skull and may extend through this fracture to become continuous with the overlying periosteum or aponeurosis. The fracture line may or may not be evident in the x-ray films of the skull. The trephine holes are placed in the usual manner to outline the bone flap and the saw cuts made as usual with the Gigli saw.

Great care must be taken, as the bone flap is being elevated, to free the dura from the bone by blunt dissection with an instrument, concave side to the skull surface. (A suitable instrument for this purpose is the No. 3 Penfield dissector.) Provided this is done carefully and conscientiously, there is little danger of trauma to the cortex, even though the dura is adherent. When the dura is absent and the cerebral cortex in contact with rough stalactite formations from the inner table (Fig. 175), irreparable

damage may be done to the cortex by a hasty or careless elevation of the bone flap. For this reason especially it is important to keep the blunt dissector in contact with the bone throughout while freeing the dura. When the operator has assured himself that an instrument can be passed between the bone and the dura beneath the entire flap, the base of the bone flap is broken back in the usual manner.

A gross defect in the skull requires a somewhat different treatment. After the incision has been made along the previously outlined flap, the scalp is reflected from the skull by sharp dissection, completely exposing the bone defect. The next step is to free the dura from the bone in the region of the defect. First a sharp circular incision of the periosteum is made from 1 to 2 mm. from the free edge of the bone. With a small periosteal elevator or dissector the periosteum is reflected from the bone toward the free edge where it becomes continuous with the dura and the meningocerebral cicatrix. By means of a curved dissector the dura about the defect is then freed from the bone flap which can then be reflected in the usual manner (Fig. 176).

The dura is frequently very sensitive in these patients under local anesthesia, and even though the local anesthesia of the scalp has been perfect the patient may complain of severe pain when dissection is carried out between the dura and the bone. When the bone has been reflected and the dura exposed, the dura can be readily anesthetized by a small amount of nupercaine solution (1 in 1,500) injected into the layers of the dura surrounding the main branches of the middle meningeal artery. The pain which the patient experiences in the difficult period before the dura is anesthetized can be mitigated in several ways. First, the dura must not be compressed or handled more than is absolutely necessary. Second, the bone flap must be separated and reflected as rapidly as possible. Third,

small pieces of dental roll soaked in nupercaine solution may be placed through the trephine holes near the main branches of the middle meningeal artery. Fourth, general anesthesia may be used for a few min-

brought into view, fine avascular adhesions may be encountered which can be severed with scissors. On the other hand, a dense and extensive meningocerebral cicatrix will require careful dissection with a scalpel. A



Fig. 176. Osteoplastic bone flap turned back around bone defect overlying meningocerebral cicatrix

if no gross or obvious meningocerebral adhesions have been encountered. Large subarachnoid pools of fluid, particularly in the dependent portions of the exposed cortex along the superior sagittal sinus, indicate a certain degree of diffuse cerebral atrophy (Fig 177). To obtain a better view the arachnoid may be nicked and this fluid allowed to drain away. The size of the gyri should be examined and any that are ex-

usually indicate an area of contusion, the result of rough turning of the bone flap

Along the superior sagittal sinus at the midline the attachments of arachnoidal granulations should be noted These have been thought to be the irritative focus in some cases of epilepsy (Scarff[4]) which begin in early childhood or infancy with a focal onset in the foot or leg.

7. Exploration of Cerebral Cortex by



FIG. 177. Subarachnoid pool of fluid as a result of cerebral atrophy in an epileptic brain.

ceptionally reduced or buried beneath adjacent gyri should be noted as areas of microgyria (see Penfield and Humphreys[3]). Superficial cerebral cicatrices may be observed as shallow depressions of the cortex often covered by thickened arachnoid or by an opaque mat of cicatrix with alteration of the surrounding vasculature. Small areas of bluish discoloration with petechial hemorrhage in the cortex may be mistaken for cerebral cicatrix but

Electrical Stimulation. This should be carried out to determine the situation of the precentral and postcentral gyri before any excision is done in that neighborhood. For this purpose a thyratron stimulator (Schmitt and Schmitt[5]) is quite satisfactory A unipolar or a bipolar electrode may be used Various types of A-C stimulators have also been used with success (Erickson and Gilson[6]).

When the sulcus of Rolandi has been

vomiting cease, since these acts raise the venous pressure. If long-continued parenteral fluids are necessary, 5 per cent glucose solution in distilled water is preferable. An excess of sodium chloride above that lost by vomiting or hemorrhage should be avoided, since such an excess is known to favor the development of cerebral edema.

Postoperative Hemorrhage. Signs of postoperative hemorrhage should be carefully watched for—slowing pulse, advancing paralysis, progressive drowsiness, rising systolic blood pressure, and increasing pulse pressure. Reopening of the wound and evacuation of the clot should be carried out before the terminal signs of dilatation of the pupil and Cheyne-Stokes respiration occur. Cerebral edema may present a somewhat similar picture, but it may be distinguished by the slower evolution of neurologic signs as well as by inspection of the incision and by lumbar puncture. Daily lumbar puncture not only enables one to record accurately the occurrence of any dangerous increase of pressure; but the removal of fluid, so that the pressure falls to half of the original value, often produces relief.

Postoperative Epileptic Seizures. The occurrence of epileptic seizures in the immediate postoperative period is a bad sign as far as eventual freedom from attacks is concerned. It may be an indication for reopening of the flap and extension of the area of excision. Increased drowsiness and post-ictal paralysis following such seizures may be misinterpreted as cerebral edema or hemorrhage if careful observation is not made.

Patients with epileptic seizures due to an atrophic cerebral lesion have invariably received anticonvulsant medication before operation but without relief from their seizures. Even though an epileptogenic focus be completely removed at operation it is well to continue this medication for six months or a year after operation so as to combat the constitutional susceptibility to epilepsy which is present to a greater or lesser degree. One is usually guided by the previous response to medication, but in the average patient phenobarbital (gr. i b.i.d.) or dilantin (gr. 1.5 t.i.d. a.c.) should be given as soon as the patient is able to take liquids by mouth.

Pulmonary Complications. Although relatively rare these complications should be suspected whenever there is a sudden increase of respiratory rate, dyspnea, or cyanosis. Routine postoperative prophylactic measures, such a frequent turning of the patient (every one to two hours) and drainage of secretions from the upper respiratory tract by posturing or by aspiration, are most important. If a pulmonary atelectasis develops in spite of these measures they should be intensified with particular attention to posturing of the chest, combined with vigorous percussion to dislodge the substance blocking the bronchi. Removal of the mucus by bronchoscopy may be occasionally necessary. A rebreathing bag should be employed every 15 minutes to induce pulmonary hyperventilation. Oxygen administered by nasopharyngeal catheters or by a tent should be used if cyanosis is not promptly cleared up. One of the sulfonamides may be advisable.

Postoperative Wound Infection. This is a complication especially to be feared. Several factors predispose to its occurrence. Meningocerebral scars as the result of healed brain abscess or of penetrating wounds may continue to harbor pathogenic organisms for many months. If possible a proper interval should be allowed to elapse before undertaking removal of the cicatrix, and prophylactic doses of a sulfonamide should be given. The mastoid air cells or the paranasal sinuses may be opened accidentally during reflection of the bone flap. This can usually be avoided by careful study of the skull x-rays and planning of

the bone flap. If the frontal sinus or mastoid air cells are accidentally opened, a piece of dura or fascia should be firmly sutured over the opening or if small, it may be closed with bone wax. Another source of infection is that due to air-borne particles settling on the wound during the relatively long procedure of exploring and stimulating the cortex, together with excision of the cicatrix. Protection of exposed parts of the wound by a sterile membrane such as pliofilm, copious irrigation with Ringer's solution, and decreasing the operating time help to diminish this hazard.

If infection occurs beneath the galea aponeurotica, the wound should be widely opened and the bone flap removed. Every effort must be made to prevent the infection from involving the meninges and one of the sulfonamides should be given in large doses. The general principles involved are similar to those elsewhere in the body and need not be discussed in detail.

**Delayed Wound Healing.** This is an annoying postoperative incident. Though it may not threaten the patient's life there is the constant threat that it will lead to a more serious breakdown of the wound, as well as delay convalescence. Attention to small details in the physiology of wound repair will serve to prevent its development. There are certain small errors which are often responsible. Sometimes the forceps attached to the galea will cause excessive pressure on the skin, and the ischemia so produced during a long operation will lead to subsequent necrosis of the skin edge. An excessive use of the electrocautery close to the epidermis may be responsible. Wound edges which are allowed to dry out during a long procedure may show delay in healing. Other causes are sutures that are too tight, recent and excessive x-ray therapy, and superficial skin infection, as well as extreme tightness of the head dressing producing an interference with the circulation of the scalp.

**Aseptic Meningitis.** Aseptic meningitis, so-called, is a complication seen after the removal of cerebral cicatrices as well as after craniotomy for other reasons. Clinically it is characterized by an elevated temperature, often in the form of recurrent bouts of fever, stiff neck, headache, and confusion, together with elevated protein and leukocytosis of the cerebrospinal fluid. Repeated cultures and smears fail to demonstrate any organism and the patients with this syndrome usually recover fully. In the Montreal series of craniotomies for epilepsy there has been only one death ascribed to this cause. Several patients who exhibited this syndrome have continued to be completely free from seizures after operation, so it cannot be considered as precluding a favorable result. The most common cause would seem to be a drainage of breakdown products of blood or other tissue into the cerebrospinal-fluid system (Finlayson and Penfield[3]). A large opening into the ventricles also seems to render the patient more susceptible. It is conceivable that in some cases the syndrome is due to an as yet unidentified organism of low virulence.

## RESULTS OF EXCISION OF ATROPHIC CEREBRAL LESIONS

The excision of cerebral and meningocerebral cicatrices has been shown to be successful in as far as the cerebral lesion or lesions can be found and completely removed. In a series of 154 patients who were carefully traced for periods ranging from one to ten years after operation (Penfield and Erickson[1]), the following results were observed. With excision of a meningocerebral cicatrix 45 per cent of the patients showed a marked improvement and an additional 32 per cent a moderate improvement, making a total of 77 per cent who were considered to show a definite improvement. With excision of a cerebral cicatrix 40 per cent of the patients were

markedly improved while an additional 19 per cent were moderately improved, making a total of 63 per cent with a worthwhile improvement.

A control group, consisting of patients in whom a craniotomy was done but no significant focal lesion was found, showed a marked improvement in only 5 per cent of the patients. The results obtained in this latter group of negative explorations proved three things: first, that a simple craniotomy, even when accompanied by a decompression, does not produce improvement; second, that the improvement in the former two groups was due to the excision of the lesion and not due to altered or improved medical treatment, for all three groups were similar in this respect; and third, that the incidence of spontaneous remission in this type of epilepsy is 5 per cent or less. The operative mortality in the entire series was 4 per cent, and 2 per cent of the patients considered that they were worse after operation.

The removal of cerebral neoplasms or expanding lesions in patients with epileptiform seizures results in a "cure" of seizures in about the same percentage of patients as following excision of cerebral cicatrices. If the seizures continue after operation one must suspect a recurrence of the neoplasm or a contracting cicatrix following its removal. The same is true when the seizures occur for the first time after operation for removal of an expanding lesion.

Factors Influencing Prognosis Following Surgical Excision of Cerebral and Meningocerebral Cicatrices. Age has no demonstrable effect on the ultimate result of operation for excision of the meningocerebral cicatrices.

The location of the cicatrix appears to have a definite effect on the results of excision. Seventy per cent of the patients who were greatly improved or cured by operation had cicatrices in the frontal region,

while only 18 per cent had scars in the parietal region. This is in contrast to the groups of patients who were unchanged by operation, among whom there were 36 per cent frontal and 55 per cent parietal scars. The number of cicatrices in the occipital and temporal regions, although relatively too few for absolute conclusions, showed no significant difference. The conclusion can be drawn that meningocerebral cicatrices in the frontal region are more likely to show a good result or "cure" following surgical excision than those in other regions. The reason for this undoubtedly lies in the fact that frontal-lobe cicatrices can be more completely and radically removed than those in other regions of the brain.

The duration of attacks preoperatively has no demonstrable effect on the prognosis following excision of a meningocerebral cicatrix. That such is the case can be illustrated by reference to two cases. One patient who had had severe frequent seizures for 17 years prior to excision of a frontal-lobe meningocerebral cicatrix has been entirely free from fits during the five years which have elapsed since his operation. Another patient of similar age with fits for only six months prior to operation showed absolutely no change following excision, albeit not a satisfactory excision.

The frequency and severity of seizures has no apparent effect on the outcome following excision of the cicatrix. These findings are not necessarily incompatible with the view that each seizure leaves its trace in the brain. The changes secondary to the fits which occur in the hippocampus and cerebellum (Spielmeyer[9]) are not directly concerned with the pathogenesis of the epileptic seizures, while those progressive changes in the cicatrix and its neighborhood as described by Penfield and Humphreys[3] are local and hence will be relieved by surgical excision.

If, however, there are marked mental changes associated with epilepsy, the

chance for alleviation of the fits seems to be definitely lower unless the lesion is absolutely localized. Patients with mental changes and meningocerebral scars have a better prognosis for relief of both the mental disturbance and the fits than those patients with cerebral atrophy or cerebral cicatrices.

In general it may be stated that the occurrence of seizures in the immediate postoperative period speaks for a poor prognosis as to ultimate cessation of the attacks. Other complications, such as cerebral edema and postoperative hemorrhage, do not influence the prognosis adversely, provided they are properly handled.

## SURGICAL TREATMENT OF CRYPTOGENIC (IDIOPATHIC) EPILEPSY

When no gross pathologic change can be demonstrated by the usual thorough clinical investigations combined with the special technic of pneumo-encephalography and electro-encephalography, the patient may be said to have cryptogenic (idiopathic) epilepsy.

A variety of surgical procedures, such as radical colectomy, oophorectomy, and adrenalectomy, have been widely practiced in the past and in the treatment of epilepsy have been found to be worthless. Operations for the removal of a focus of infection have rarely influenced the seizures. Such procedures are justified only when the existence of a focus of infection can be definitely proved.

Sympathetic ganglionectomy has been repeatedly tried as a cure for cryptogenic epilepsy. The trial has been sufficiently long to justify the conclusion that sympathectomy is a failure unless there is a demonstrable abnormality of the sympathetic nervous system. Carotid sinuneurectomy has also been carried out in several series of patients with cryptogenic epilepsy but without benefit. It is to be recommended only when there is a definite abnormality of the carotid sinus mechanism.

Encephalography with oxygen or air results in the cessation of seizures in a small percentage of cases. The good results are almost all in children under the age of 16 years. Subtemporal decompression has been tried by numerous surgeons, but there is no benefit to be derived from the procedure unless the seizures are secondary to a subdural effusion or associated with a craniostenosis.

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SECTION FOUR

# SPINAL CORD

# 17

# Surgery of Spinal Cord

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When Sir Victor Horsley successfully extirpated a tumor of the spinal cord in 1887, his imagination could hardly have anticipated the number of spinal operations performed today. Spinal tumors may be found from occiput to coccyx. Congenital malformations are all too common. Fractures and dislocations of the spine have increased in number and protrusions of the intervertebral disks are the first thought in sciatica. The abscesses and granulomata, though less frequent, have their place. Section of pathways and division of roots for the relief of pain, spasticity, and contractures are common procedures.

Few accomplishments are of greater value to the patient ·or more satisfying to the surgeon than the permanent restoration of a bedridden paralytic to a normal and useful life. The knowledge of neurologic localization, supplemented by that obtained from spinal puncture and the Queckenstedt test, the injection of radiopaque material or of air, and the advances in roentgenologic technic permit an accuracy of diagnosis seldom attained in other regions of the body. Tumors affecting the cord and cauda equina are sufficiently common to have afforded us a considerable familiarity with the pathologic types. Fortunately, a high proportion of these new growths are amenable to surgery and the majority are benign.

In the surgical treatment of injuries, on the other hand, the neurologic surgeon becomes very conscious of his limitations, for he is dealing with destructive damage. If nervous tissues were as capable of regeneration as are the vertebrae, the results in the care of those paralyzed because of spinal injuries would be as brilliant as the reconstruction of bony injuries achieved by our orthopedic confreres. The spinal cord, however, does not regenerate, and our efforts must be directed toward minimizing the damage already done and preventing further injury.

Growth and development may add complications to congenital malformations which are already bad enough. By plastic operations the surgeon may improve the appearance of these malformations, correct some of them, and prevent progressing paralysis. He is unable, however, to complete the task Nature, in developing the nervous system, left undone.

Infections which localize within and about the spinal canal are relatively infrequent, but, in the form of abscesses or granulomata, occasionally manifest their presence and require operation. In the absence of infectious thromboses, prompt

surgical treatment is indicated in rapidly progressive compressions. Much greater accomplishments may be expected from the use of the recently added chemotherapeutic aids.

By reason of detailed knowledge of neuro-anatomy and neurophysiology, certain operations have been developed for the control of pain. Interruption or division of sensory nerve roots supplying an area (rhizotomy) has been largely replaced by the division of these pathways conveying painful sensations (chordotomy and myelotomy).

These various types of surgical conditions involve some differences in technical management. The methods discussed below may be considered basic; their variations will be commented upon in subsequent chapters.

## GENERAL CONSIDERATIONS

Under present operative methods, the mortality from spinal operations should be very low. Technical improvements have reduced bleeding and the risks are chiefly those incident to any major operative procedure. Some special hazards may be mentioned; respiratory difficulties may be anticipated in association with some spinal lesions such as tumors in the midcervical region. Sepsis from infections of the urinary tract and decubitus may be complications before or after operation. Septic patients and those with metastatic or other advanced disease present special problems. Maintenance of water and electrolyte balance, the correction of vitamin deficiencies, and hypoproteinemia are factors to be considered in the nutritional state of these patients and constitute a preoperative obligation which continues through the operative and postoperative periods.

## PREPARATION OF FIELD OF OPERATION

For elective operations, such as those for neoplasm, malformations, protrusions from the intervertebral disks, and chordotomy, the method of preparation of the skin involves no special modification of usual technics. Inspection of the skin for pustules or other evidences of infection and for decubitus should be made the day preceding operation.

Because of the marked downward inclination of the spinous processes, particularly in the thoracic region and to a lesser extent in the cervical region, the body of a vertebra lies more cephalic than the spinous tip of its lamina. Furthermore, the corresponding segments of the spinal cord lie higher than the vertebrae of the same numerical designation. The inclination of the spinous processes is greatest in the midthoracic region. When the injection of lipiodol and x-ray studies have shown clear evidence of exact localization, it is advantageous to mark the overlying skin indelibly before operation.

On the day of operation, a wide area about the proposed field is shaved; this is followed by thorough and prolonged scrubbing with soap, water, alcohol, and an antiseptic. The line of incision is scratched and is cross-hatched at the level of the lesion. The field is then draped so as to leave but little skin exposed. Gray, blue, or green coverings are superior to white as they prevent the annoying glare consequent upon white drapes and help to avoid undue contraction of the surgeon's pupils.

## ANESTHESIA

For tumors involving the spinal canal and for most other spinal conditions, general anesthesia is preferable. As a rule, preliminary medication of morphine and atropine is administered one hour before the operation, for which ether is generally used. Though avertin supplemented with a little ether or nitrous oxide and oxygen has been employed frequently, it is doubtful that any anesthetic agent surpasses ether

alone, for most procedures. Exception may be taken to the use of morphine or atropine and to avertin for cervical lesions in which the phrenic innervation may be affected. In special instances and for operations of limited scope, such as the removal of a protrusion from an intervertebral disk which has been localized accurately, or when the cooperation of the patient is desired, as in

will be spared postoperative discomforts and so-called anesthetic palsies, and exposure will be more readily obtained by the surgeon if a proper position for the patient is achieved. Hyperextension of joints should be avoided and the posture must be one permitting the anesthetist to work to the best advantage. Some surgeons prefer to have the patient in a lateral or semi-
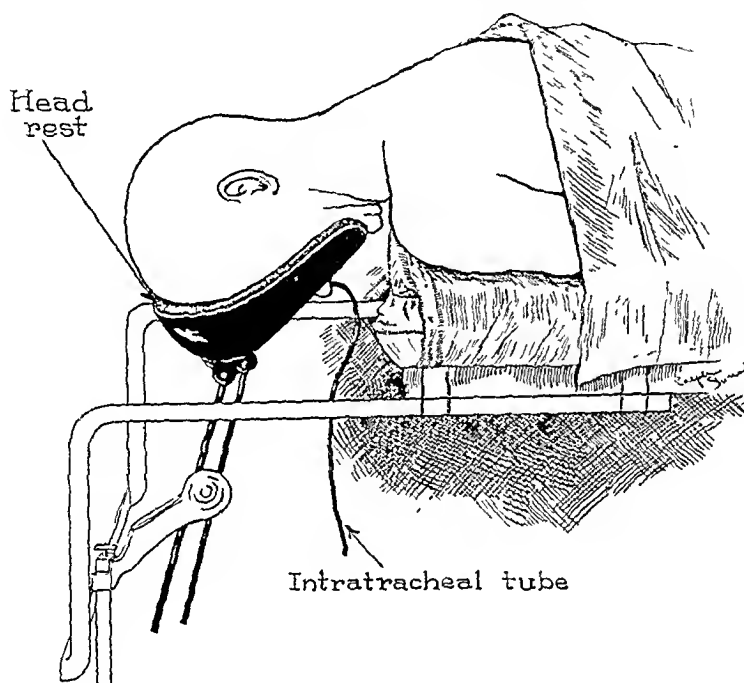


FIG. 178. Position for cervical laminectomy.

chordotomy, local anesthesia (0.5 or 1 per cent procaine hydrochloride containing three or four drops of adrenalin to each 30 cc.) is satisfactory. Intratracheal anesthesia has great advantages in cervical cases in which marked flexion of the neck is to be maintained.

## POSITION OF PATIENT

As for many other operations, proper attention to the details of the patient's position on the table is one of the most important steps and should not be left to an inexperienced junior assistant. The patient

lateral position rather than prone. Though it has the advantage of permitting fluids to drain away from the field, this position is not generally adopted. As a rule the patient should lie face down with the knees slightly flexed by a pillow under the ankles. Support under the abdomen prevents undue lumbar lordosis and consequent pain in the back after operation.

Certain portions of the spinal canal present individual difficulties. For operations upon the high cervical spine, for example, a cerebellar headrest with a horseshoe-shaped support for the face is required.

For some patients shoulder crutches will maintain better position and allow freer respiratory movements. Considerable time may be spent to advantage in securing and retaining a satisfactory position of the head and neck in marked flexion with the chin upon the chest (Fig. 178). This must be accomplished without interfering with respiration. In such a position intratracheal anesthesia is of greatest value. Pressure on the larynx or trachea just above the manubrium must be avoided. If extension of the head on the neck and the neck on the thorax is permitted, the cervical spinal processes will be in juxtaposition and the

slightly, which will allow adequate access for the anesthetist.

In the lumbar region the convexity of the spine is again anterior. The laminae lie deeply and the muscles may be extremely heavy. For operations upon this region, particularly the lumbosacral junction, the prone position has been found most satisfactory. The table must be angulated or the abdomen be so supported as to flatten the spine and obliterate the lordosis (Fig. 179).

For all major operations it has been for years the authors' custom to insert a needle into one of the veins of the foot, prior to
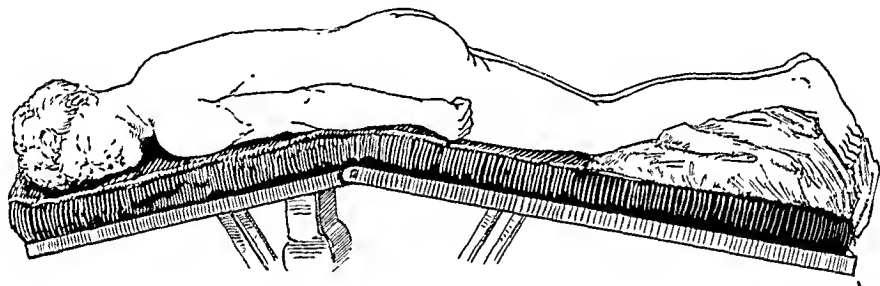


FIG. 179. Position for lumbar laminectomy.

overhanging occiput will make a satisfactory exposure for cervical laminectomy impossible. The anterior convexity of the cervical spine adds to the difficulty by placing the spine even more deeply. Particularly for cervical laminectomy, as for cerebellar operations, a sitting position with special support has many advantages.

Most easily exposed is the upper thoracic region where the convexity of the spine is posterior and the vertebrae are not placed so deeply. The erector spinae muscles are thinner and are more readily cleaved from the spinous processes and laminae. The spinous tips are more easily freed from muscle and periosteum than are the irregular bifid spinous tips of the cervical region. In exposing this and lower portions of the spine, the cerebellar headrest is not required. The patient's head may be turned

operation, for the ready administration of fluids.

## OPERATIVE TECHNIC

For obese persons and those with thick subcutaneous tissues, longer incisions are required. The straight incision in the midline is most satisfactory. Bleeding may be controlled by manual pressure on the sides of the incision until hemostats are placed (Fig. 180). Use of the electrosurgical unit permits many hemostats to be discarded shortly.

With the cutting current the fibrocartilaginous tips of the spinous processes are split and the deep fascia in the midline, connecting these tips, may be divided in the same way. With a very sharp periosteal instrument, separation of the fibrocartilage from the spinous processes, as well as sub-

periosteal separation of the muscles from the sides of these processes, is carried well down onto the lamina. Before the instrument is withdrawn, a gauze tampon is inserted into the depths of the wound and packed snugly (Fig. 181). This procedure

because of the free bleeding associated with incisions made into the muscles alongside the spinous processes.

The exposure should extend laterally to the articular facets (Fig. 182). With bone shears or rongeurs the spinous processes
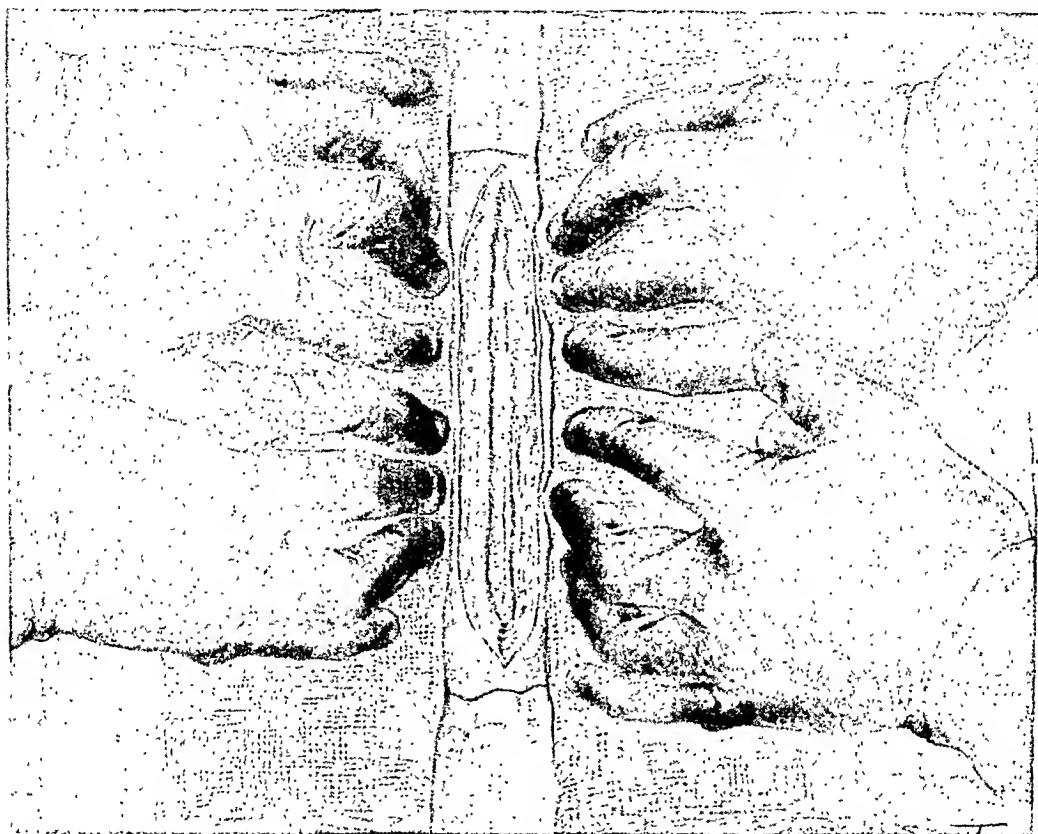


FIG. 180. Manual control of bleeding.

is repeated on both sides of each spinous process.

Any intervening small attachments of the erector spinae muscles are then divided and hot packs are introduced. Removal of these packs should show spinous processes and laminae cleanly freed of bony and muscular attachments. Before the value of subperiosteal separation of the muscles was appreciated, laminectomy had a deservedly bad reputation as a very bloody operation

are cut free at their bases and removed. The laminae are bitten away with curved and straight rongeurs, beginning with the lower edge of each lamina. The bone is removed first in the midline and then laterally to the articular facets (Figs. 183, 184). In the cervical region it is especially important not to remove or damage the facets as the tendency to later dislocation is increased. In other regions also adequate exposure for most purposes can be obtained

without the removal of facets except in oc-
casional instances in which a wider expo-
sure is desired at the exact level of the
tumor. For example, in the thoracic and

When removing the lateral portions of
the laminae, extradural veins are occasion-
ally torn. Bleeding from these may be con-
trolled by cotton packs, or by pieces of
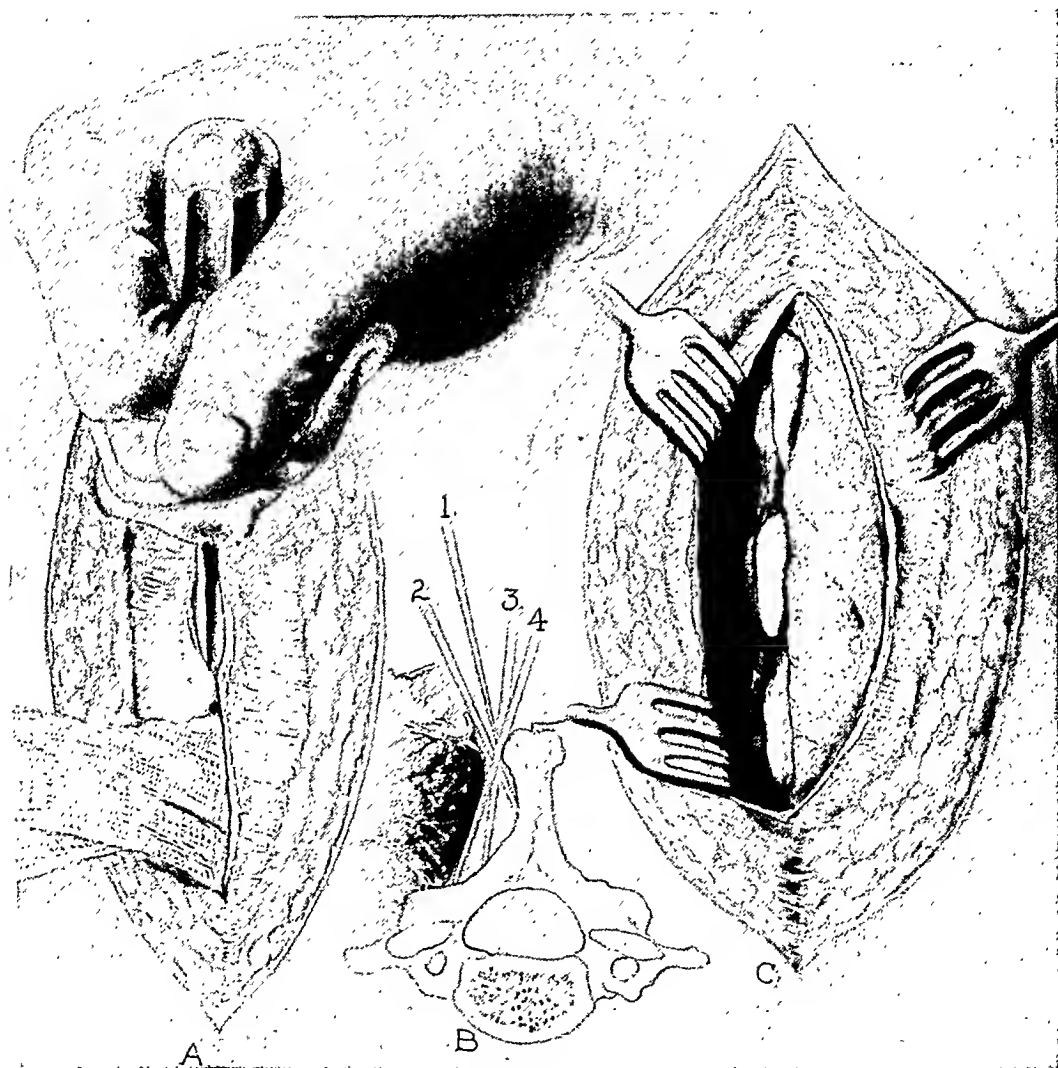


FIG. 181. Subperiosteal separation of muscles from spines and laminae.

lumbar regions, large tumors with attach-
ments difficult of access may require the
removal of articular facets. No postopera-
tive difficulty has been experienced in these
cases and it is possible that the danger of
such removal has been overestimated.

gelatin foam or fibrin foam soaked in
thrombin solution, care being taken not
to exert any great compression on the
dura, or the veins may be coagulated or
clipped directly. The ligamenta flava,
which are particularly heavy in the lumbar

region, are attached to the upper margin of each lamina, but pass up under the one above to attach to its under surface at about its middle. These ligaments are ex-

canal may be extradural or intradural and the latter may be intramedullary or extra-medullary. In dealing with an intradural lesion, as soon as adequate exposure is ob-
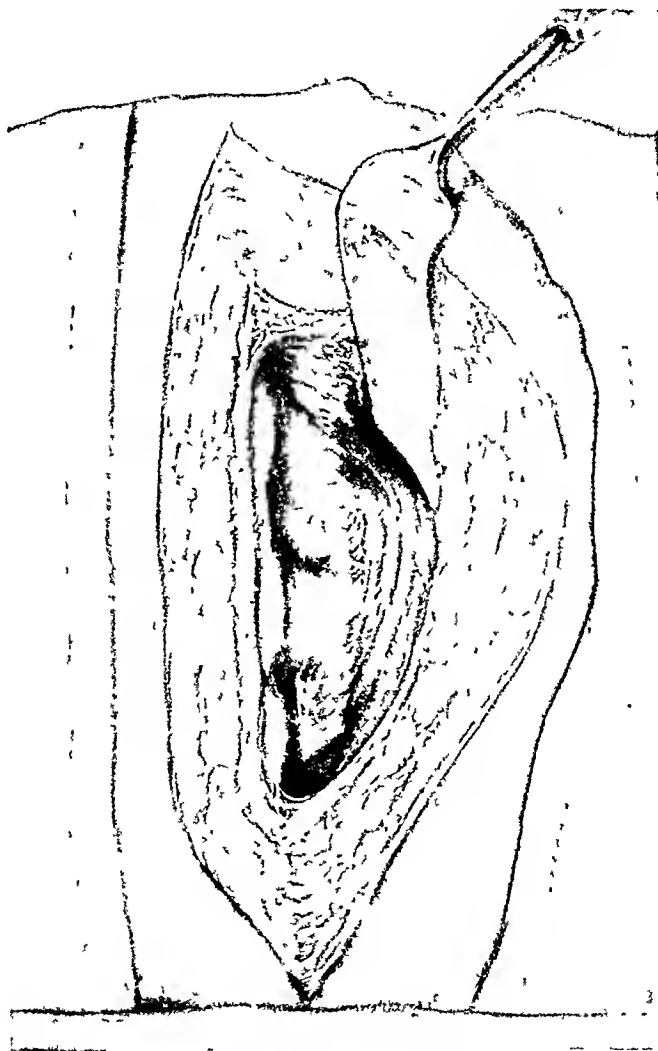


FIG. 182. Unilateral exposure.

cised from their attachments and cut away. The extradural fat and the cellular tissue in the midline are split and separated. Oozing from the cut edges of the bone requires the use of bone wax.

The tumors found within the spinal

tained, the dura is carefully inspected for color, pulsation, and distention, and is lightly palpated for any underlying mass Complete hemostasis must be obtained before the dura is opened; any entrance of blood into the dural canal is most unde-

sirable both because it obscures the field and because it is productive of later adhesions. This hemostasis is accomplished best by strips of gelatin foam soaked in throm-

on wire needles, these sutures serving as retractors to separate the dura from the arachnoid (Fig. 184). The dura is carefully incised with the belly of the knife so



Fig. 183. Removal of spinous processes—full exposure.

bin and laid along the sides of the dural exposure. These are not disturbed subsequently, the material being readily absorbed without clinical evidence of reaction. The outer layers of the dura are picked up with fine silk or cotton sutures

that it may be opened without injuring the arachnoid. The opening is enlarged by cutting on a grooved director, and additional traction sutures are placed, or the dural margins may be temporarily stitched to the muscles. If the incision is below the

site of compression of the cord, pulsation probably will not be seen  Additional evidence that the block is higher may be ob-

the block is complete no increased flow of fluid will be noted

Additional confirmation of the presence
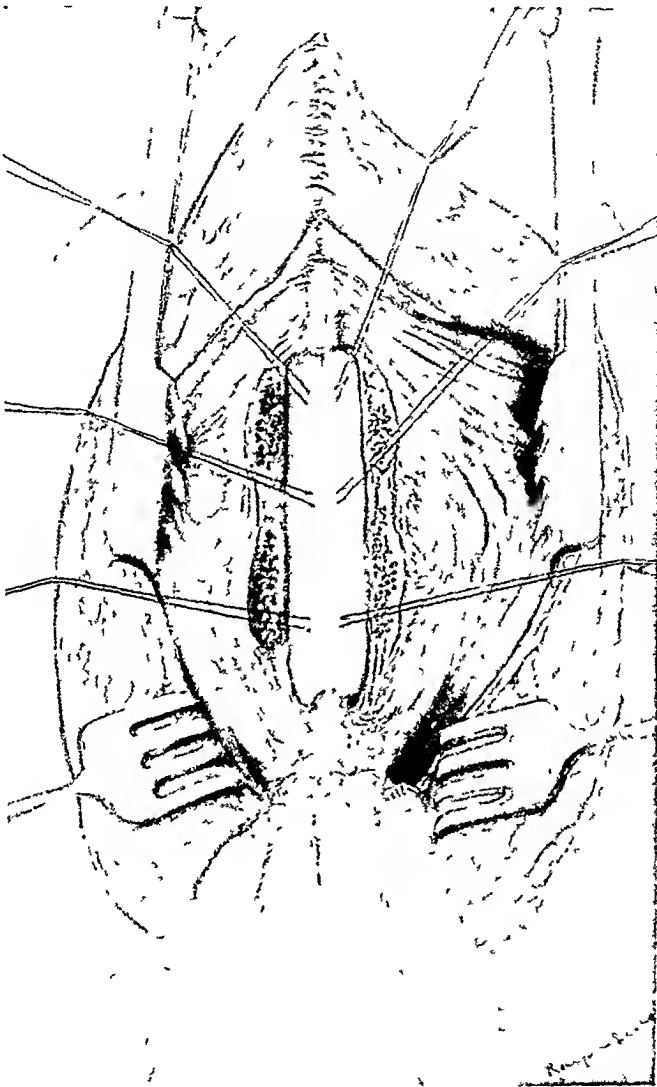


FIG. 184. Full exposure of dura by removal of laminae; traction sutures in the dura.

tained by having the anesthetist compress the veins of the neck. If the arachnoid has been opened the fluid will flow out readily, unless there is a block above. If

of a block above or below the level may be obtained by inserting a small, smooth, soft-rubber catheter between the arachnoid and the dura for considerable distances up
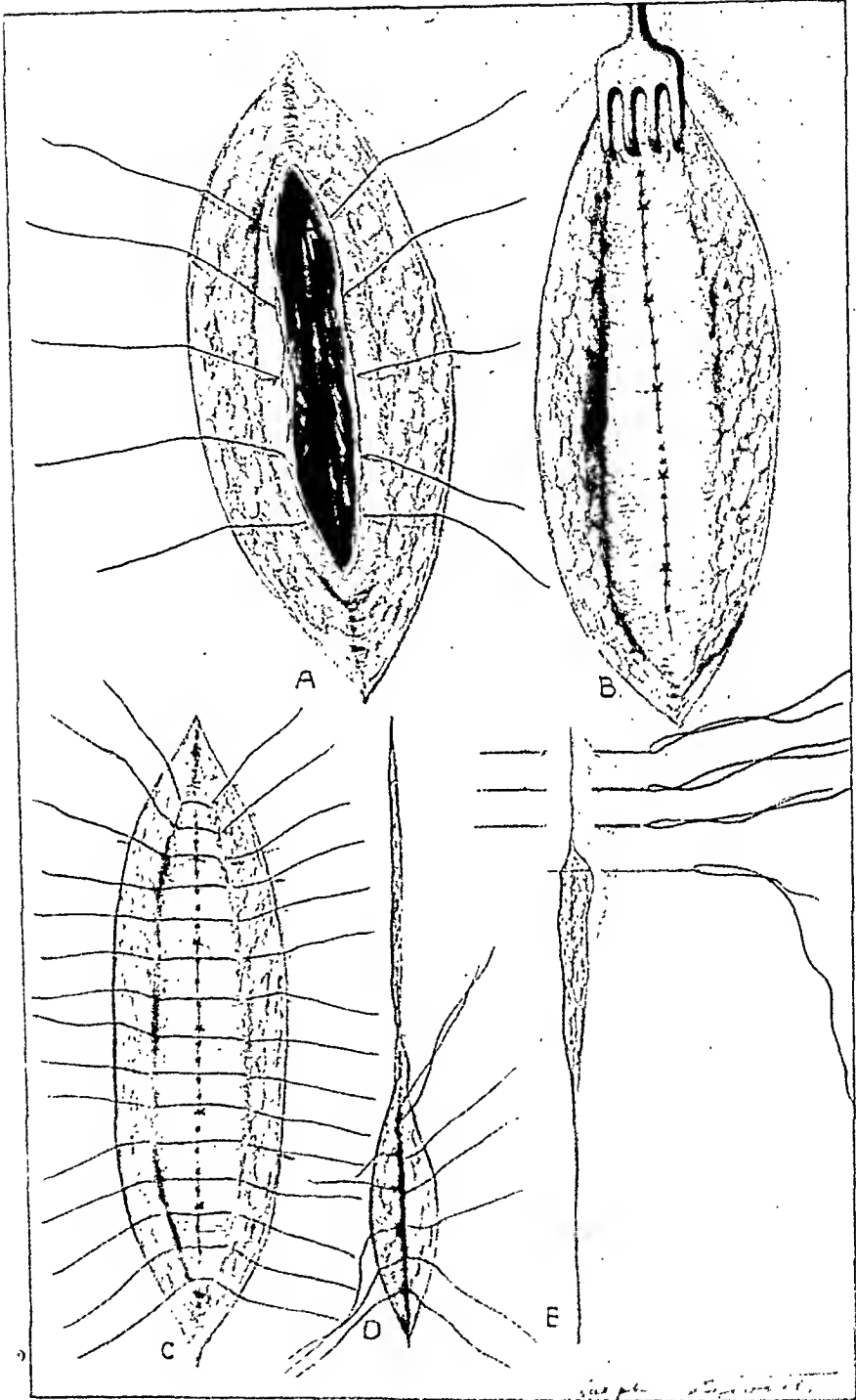
FIG. 185. Closure of muscles, deep fascia, subcutaneous tissues and skin.

and down the canal. Manipulations must be gentle to avoid damage to the spinal cord. Opening of the arachnoid is followed by a free flow of fluid which may be removed by suction, after which the cord, its vessels, the nerve roots, and the dentate ligament are plainly seen and any displacement of the cord posteriorly or laterally may be observed. A dentate ligament, severed from its connections with the dura, may be used to rotate the cord, permitting inspection of the ventrolateral surface of the dural canal.

At the conclusion of the operation Ringer's solution is used to wash the dural canal completely free of all traces of blood. When no excision of dura has been necessary it is closed completely. A continuous suture of fine silk or cotton on a small wire or French needle may be used, or, if interrupted sutures are preferred, they should be placed close together and a watertight closure obtained. Hemostasis of the muscles, laminae, and extradural fat being complete and the retractors having been removed, the muscles will fall well together. With proper hemostasis drainage is never required except in the presence of infection. In clean cases the authors' preference is for the use of silk or cotton sutures throughout. For the muscles and deep fascia, medium sutures are placed at intervals of 3 cm., supplemented by fine sutures between them. Fine material is likewise used for the subcutaneous tissues and the skin (Fig. 185).

Incomplete closure of the dura may result in spurious meningocele with pain and tenderness, requiring secondary operation, or a cerebrospinal fistula with its attendant dangers may result. If complete closure is impossible, as in those instances in which resections of the dura have been required because of involvement by a neoplasm, the utmost care must be taken to insure tight closure of the deep fascia.

In dealing with abscess or granuloma the deep fascia and muscles may be brought together with a few interrupted sutures of silver, steel, or tantalum wire, or chromic catgut. Firm material in which to place such sutures is found in the remainder of the split fibrocartilaginous caps of the spinous processes. Supplementary sutures for approximation of the muscles and deep fascia are of catgut with similar material for the subcutaneous tissue, followed by the surgeon's choice of sutures for the skin.

After closure of the skin, flat gauze dressings, thicker on each side of the incision, are placed and strapped to prevent wrinkling, dislodgment, or contamination. Dressings of the same thickness (or even slightly thicker) are applied over the areas immediately above and below the wound, thereby avoiding a painful degree of pressure on the operative site. The whole is covered with a flat cotton pad, held in place with adhesive tape, and oiled silk is used as a final covering. It has been the authors' custom to place the patient on his back. Formerly, an air mattress under low pressure so that it would conform to the curves of the body was used exclusively. Recently, however, mattresses have been sufficiently improved so that the use of an air mattress seems less important. Supporting pillows under the knees and calves flatten the lumbar spine and add to the patient's comfort.

When the extremities are anesthetic, properly placed pillows under the thighs, knees, and calves remove some weight from the trunk and lessen the likelihood of decubitus. These supports extend down to the tendo achilles. The heels should not rest on the bed (Fig. 186).

Recommendations for modification of laminectomy have been made. Unilateral laminectomy, involving removal of bone between the base of the spinous process and the articular facets on one side only, was recommended by Taylor. Only the bone between the base of the spinal proc-

ess and the articular facets is removed (Fig. 187). For rhizotomy and certain limited and well-localized lesions unilateral esses and the interspinous attachments. After a subperiosteal separation of the fascia and muscles from only one side of
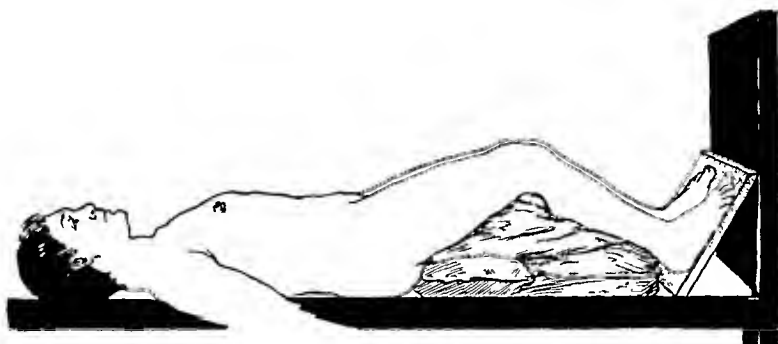


Fig. 186. Position of patient, with support of anesthetic extremities.



4<sup>th</sup> cervical

A

B

7<sup>th</sup> dorsal

C

3<sup>rd</sup> lumbar
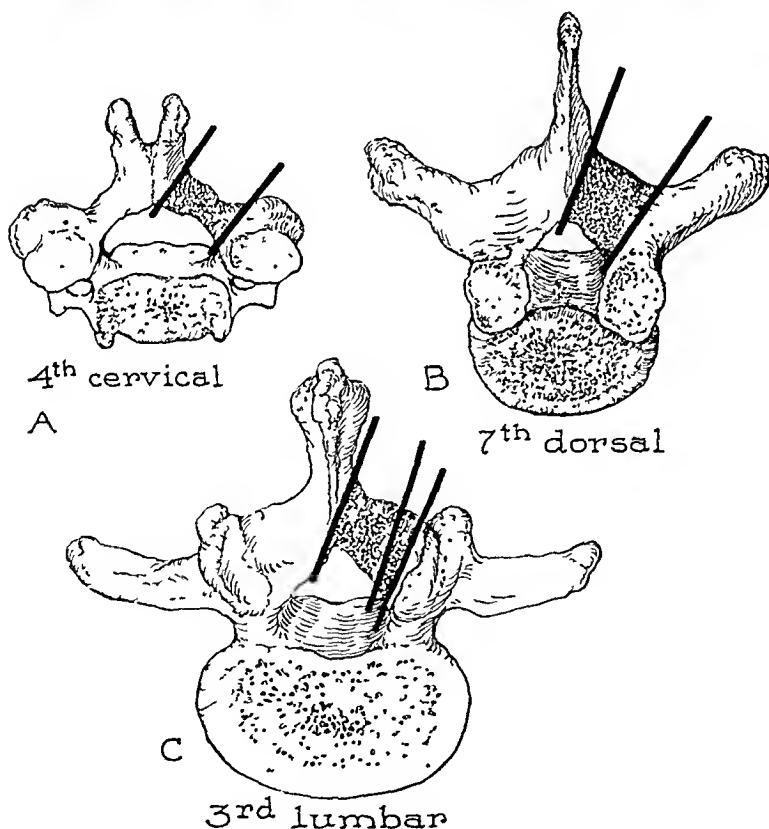
Fig. 187. Unilateral laminectomy.

laminectomy has proved satisfactory, particularly in the cervical region. Mixter has advocated the retention of spinous proc- the spinous processes, these processes are cut at their bases and retracted to the opposite side with the attached muscles.

From this stage on the usual laminectomy is performed.

## DIAGNOSTIC AIDS

### QUECKENSTEDT TEST

A positive Queckenstedt test demonstrates interference with the flow of fluid between the cerebral spaces and the site of between the fourth and fifth lumbar vertebrae. Through the sterilized skin a spinal puncture is performed, and immediately upon withdrawal of the stilet a small-bore glass manometer registering in millimeters of water is connected. Normal pressures vary widely, but they usually range between 100 and 150 mm. of water The
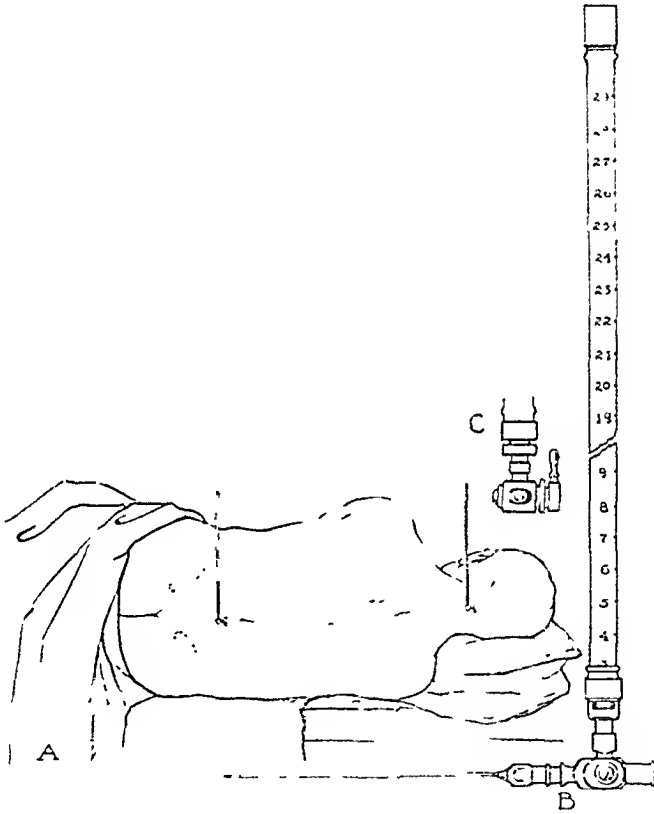


FIG. 188. Combined puncture.

spinal puncture. The obstruction may be partial or complete and indicates some mechanical blockage in the spinal canal such as might be caused by tumor, adhesions, or compression of the entire dural canal from any cause.

The patient is placed horizontally on the left side with hips flexed. A small pad under the side of the head raises the occiput to the level of the interspinous space

fluid column will show minor rhythmic variations caused by respiration and pulse, and will respond readily to cough, straining, and abdominal compression. Such reactions are the result of an elevation of intra-abdominal venous pressure which is transmitted readily to spinal veins. These observations also confirm the patency of the needle.

To perform the Queckenstedt test, the

patient's neck is compressed with the hands or by the cuff of a sphygmomanometer. A normal reaction is a prompt rise of the spinal fluid to a level usually between 250 and 400 mm., with an equally prompt fall when compression of the neck is released. Absence of or delay in the rise indicates complete or partial block. With graduated compression of the neck using a sphygmomanometer, the time and degree of change in spinal-fluid pressure may be recorded graphically by the method of Grant and Cone. This has the advantage of permitting an objective comparison of the results of punctures.

Other more complicated methods of al-

indicate lack of free circulation of fluid in the canal.

### USE OF RADIOPAQUE SUBSTANCES

Lipiodol. For the accurate localization of partial or complete blockage in the spinal canal, from 2 to 4 cc. of lipiodol may be injected by spinal puncture. This iodized oil is not absorbed, is heavier than spinal fluid, and produces cellular reaction of moderate degree. By inclining the patient on the fluoroscopic table the flow of the material in the canal may be followed to the point of blockage or be seen to wend its way around a partial block. The observations may be supplemented by "spot"



FIG. 189. Thoracic meningocele and lumbar myelomeningocele.

tering intracranial pressure (the amyl nitrite test of Elsberg) have been advocated.

Formerly combined punctures of the posterior cistern and lumbar spaces permitted a comparison of the alterations in pressure shown by the two manometers (Fig. 188) If the changes were synchronous, no block was present. Lack of synchronism indicated partial block, and absence of any notable reaction in the lumbar manometer signified a complete block between the two needles. This refinement of method is rarely required now, but has the added advantage of permitting a comparison of the physical and chemical characteristics of fluid removed at the two sites, and abnormal differences in pressure

films. Aspiration of the lipiodol and its removal under fluoroscopic control are then desirable.

Pantopaque. Pantopaque, which is less dense, is absorbable and shows more detail. It produces a fairly marked reaction. Though absorbable, its removal is not difficult and is recommended. Other radiopaque substances are available but are not generally accepted for use.

### AIR MYELOGRAPHY

Withdrawal of spinal fluid and replacement by air is adequate in the presence of a complete block and is at times helpful even in incomplete obstructions, but interpretation may be difficult.

# CONGENITAL DISEASES OF SPINAL CORD

### SPINA BIFIDA AND RELATED DISEASES

Spina bifida is the congenital defect resulting from incomplete closure of the vertebral canal This abnormality is usually single, but multiple centers have been described—for example, thoracic and lumbar (Fig. 189). The malunion may be limited closure of the vertebral arches, usually completed by about the eleventh week of fetal life. The lumbosacral spine, closing last, is most prone to congenital deficiency.

### SPINA BIFIDA OCCULTA

Spina bifida occulta is the term used when there is no projection of the meninges or their contents through the defect in the



FIG. 190. (*Left*) Pad of fat and ostium of dermal sinus overlying lumbosacral meningocele. Lines on skin indicate limits of associated saddle anesthesia.
FIG. 191. (*Right*) Pedunculated meningocele.

to one segment or may extend over many; rarely an associated defect may appear in the anterior wall of the canal as well

Spina bifida may be hidden (spina bifida occulta) or obvious, innocuous or part of a widespread deformity incompatible with life. Together with its related diseases it is most common in the lumbosacral region, next common in the cervical vertebrae, and least common in the thoracic spines. This incidence is related to the order of arch. It is seen most often as an incidental finding in x-ray studies of the lumbosacral region. It is usually asymptomatic, occasionally a tuft of hair or an area of dermal pigmentation overlying the defect may indicate its presence. Less frequently there is a bustle-like pad of fat which spreads widely over the lumbosacral muscles, fills in the bony opening, and even extends far into the spinal subarachnoid space (Fig. 190). Collagenous tissue may replace the

missing spinous processes and form a midline wall between dura and skin. A dimple usually associated with an underlying tube lined with stratified squamous epithelium sometimes is found with any of these variants (see Dermal Sinus, p. 352).

Filaments of the cauda equina become intimately involved in the fatty tissue or collagenous bands and, because of this anchorage, are traumatized as the upward-migrating conus medullaris exerts an ever-increasing traction upon them. This damage may manifest itself clinically by progressive lumbosacral sensory and motor loss, radicular pain, rectal and vesical incontinence or retention, or trophic ulceration.

Surgical Treatment. In the surgical treatment of spina bifida occulta, special preliminary preparation is seldom necessary. The back often will require careful shaving, even in very young patients, because of the tendency of the overlying skin to local hirsutism. Infection of the bladder, which is frequent, should be brought under control. Adjacent infected ulcerative areas necessitate the postponement of any surgical procedure in the affected region.

At operation the incision is made longitudinally between the first spinous process palpable above and the first below the defect. After the superficial fascia has been entered, a dry field can be preserved by use of the cutting current of the electrosurgical unit, which also may be used to start the exposure of the spinous processes, remembering always, however, that it is a dangerous instrument in the vicinity of the spinal cord or nerve roots. The muscular attachments to the spinous processes and laminae of the exposed vertebrae above and below the defect are separated with the periosteal elevator. The upper laminae are removed first to expose the normal dura above the lesion. Then by careful palpation the size and position of the bony

nubbins, remnants of the maldeveloped laminae, may be determined with precision. By utilizing these landmarks it is possible to establish a line of cleavage between dura and the overlying fatty or collagenous tissues. Subsequently it may be helpful to remove the caudal laminae as well. Infrequently the dura will be inseparable from the collagenous bands or it may merge with the fatty tissue of a pseudolipoma. Fibrous bands attached to the laminar nubbins of the bifid vertebrae should be cut away. It may be necessary to remove the bony cartilaginous nubbin itself as well.

Within the subarachnoid space, minor adhesions of nerve roots to the meninges may be successfully cut. The presence of dense fibrous adhesions or of conditions in which the nerve filaments are surrounded by connective tissue or fat presents a more complicated problem. Usually the principal attachments to the walls of the canal can be severed; seldom is it feasible to isolate the individual filaments as such. The filum terminale is often abnormally large and may be a very real factor in the prevention of normal ascent of the cord in the canal. The degree of tension can be demonstrated readily when the filum is sectioned. Failure to free the attachments of nerve roots to the walls of the spinal canal and to cut the enlarged filum may play a prominent rôle in the subsequent appearance of medullocerebellar traction displacement.

The wound should be closed as after any laminectomy, in layers, using some heavy and some fine nonabsorbable sutures. If the spinal subarachnoid space has been entered, special precaution to avoid leakage of cerebrospinal fluid is imperative. In applying the dressing, watertight protection of the wound from contamination by urine or feces must be provided. Even those patients who have had adequate preoperative vesical and rectal control may have a pe-

riod of incontinence following the operation.

## SPINA BIFIDA WITH MENINGOCELE

Meningocele and myelomeningocele (meningomyelocele; myelocele) are the most common of the lesions associated with spina bifida. They result from the combination of spina bifida of a varying degree with an early abnormality in the hydrodynamics of the cerebrospinal fluid, producing herniation of the meninges at the site of the osseous defect.

Simple Meningocele. This may be either pedunculated or sessile. Distribution is identical with that of spina bifida, already noted.

Pedunculated Meningocele (Fig. 191). This is present at birth as a nubbin on a stalk overlying the spina bifida. It may be soft but usually has a wall sufficiently thick to mask the fluid nature of its center. As a child grows the meningocele too may enlarge, though seldom proportionately. The sac may exhibit a tendency to diminish rather than to increase in size and in older persons may be difficult to identify. This type of meningocele is almost always completely covered with an intact normal-appearing skin. A thick layer of vascular fat and connective tissue lies between the skin and the cavity of the meningocele. The latter may contain several cubic centimeters of cerebrospinal fluid or may be no more than a slit, lined with arachnoid. Sometimes fingerlike projections of the cavity extend into the fibrous fatty mass and may even be isolated from the parent stem by an overgrowth of connective tissue (Fig. 192).

A variety of clinical and social factors may bring the patient with pedunculated meningocele to the neurologic surgeon. Ideally, there will have been adequate medical supervision permitting the selection of an optimum time for removal, and the parents or the patient will have been educated concerning the physical and social hazards of the condition, thereby avoiding many complications. More often relief is sought because the mass is irritated by or interferes with clothing, limits physical and social activity, or develops an associated painful ulcerative intertrigo. Motor and sensory changes rarely accompany pedunculated meningocele; when present they may be secondary to inability of the conus to rise properly in the spinal canal, or may result from congenital abnormalities in the cord itself.

Surgical Treatment. If ulceration has occurred about the pedunculated meningocele, as is common, the region should be shaved, the infection thoroughly eradicated, and a healthy skin maintained for at least three months before operation is undertaken. When the time for the procedure is optimum, the entire meningocele together with the surrounding tissue is prepared. The base is separated by an elliptical incision designed so that the wound may later heal with a satisfactory surgical and cosmetic result. The incision is carried down to the spinous processes above and below the defect as in the operation for spina bifida occulta. The neck of the sac is then dissected free from the bony walls and is closed at its communication with the dural canal. While pedunculated meningocele contains no nerve roots, the diagnosis should be confirmed by careful opening of the sac, small as it may be, before amputating the stalk.

Closure of the dural defect is made with fine nonabsorbable sutures. The stump should be completely mobilized by careful detachment from the walls of the spinal canal. The wound is then closed in layers with coarse and fine nonabsorbable sutures. The first dressing, at least, should have a waterproof covering.

Sessile Meningocele. This is more common than the pedunculated variety. It and myelomeningocele constitute by far the

majority of the conditions related to spina bifida, which come to the attention of the neurological surgeon. Sessile meningocele (Figs. 193, 194) consists of the domelike protrusion, dorsal to a spina bifida, of a unilocular or multilocular sac filled with
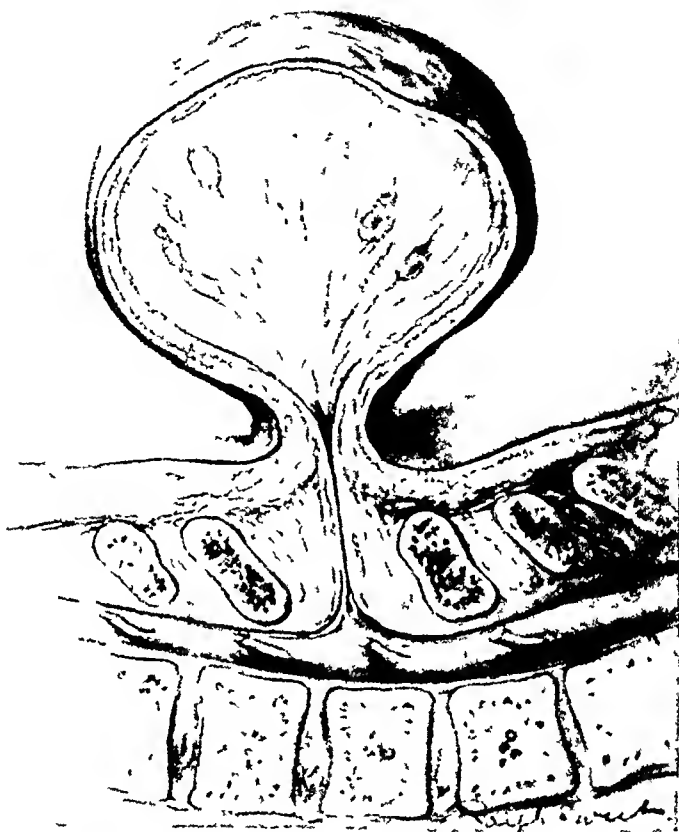


Fig. 192. Pedunculated meningocele showing small caliber of subarachnoid connection and fluid-filled lakes in fat and connective tissue of mass



Fig. 193. Lumbosacral meningocele. Note parchment-like covering at apex and normal skin at base

spinal fluid and lined more or less completely by arachnoid, dura, and skin. The opening between the sac and the spinal subarachnoid space sometimes is but a few toward the apex of the dura so that this region is covered by a thin transparent parchment which is likely to be kept moist by transudation from the contents of the
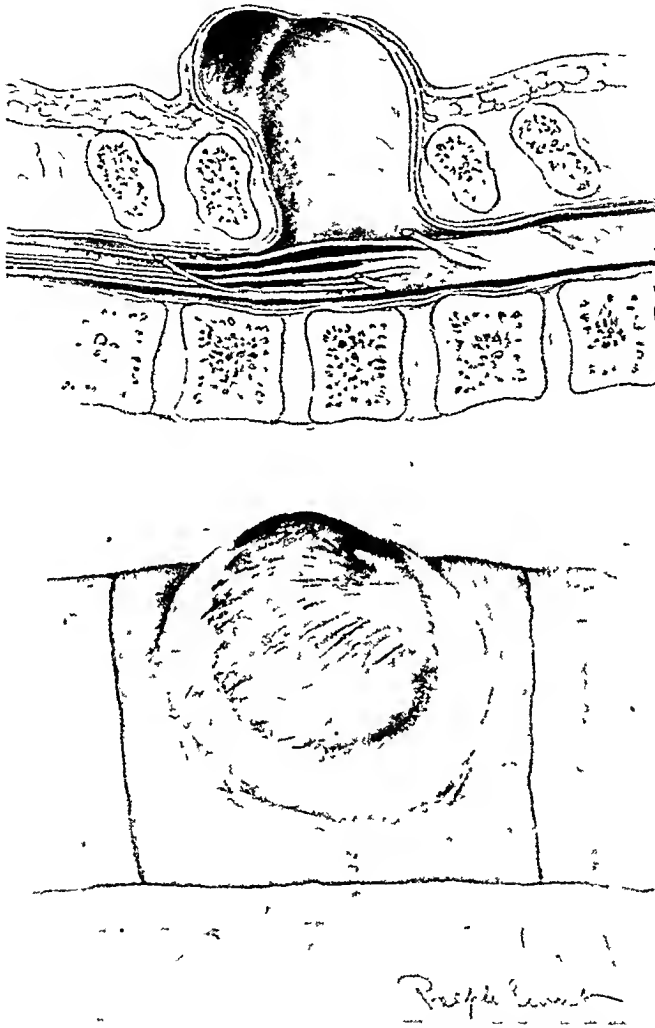


FIG. 194. Meningocele as seen at operation and by sagittal section.

millimeters in diameter; at other times it may extend along the length of several defective spinal segments. The dura and arachnoid comprising the wall of the sac may be separable or fused. In the majority of instances the skin becomes thinned out sac and therefore is easily macerated and infected Along the side of the sac the skin is usually thicker and more nearly normal in appearance and function. At the base, and for a variable distance onto the side of the sac, a layer of fat is ordinarily pres-

ent between the meninges and the skin. Occasionally such a fatty pad may cover the entire protrusion. As a rule the skin over the meningocele sac has served as a criterion for inclusion within this category. Myelomeningocele represents a greater de-



FIG. 195. (*Top*) (a) Myelomeningocele as seen at operation and by sagittal section. Attachment of cord to surface of sac is demonstrated. (*Bottom*) Rachischisis. This condition is usually incompatible with life.

such a panniculus is more hairy than the surrounding skin.

Myelomeningocele. This is "spina bifida with hernial protrusion of the cord and its meninges" (Dorland); by common usage, the presence of any nervous tissue within the meningocele sac has served as a criterion for inclusion within this category. Myelomeningocele represents a greater degree of developmental fault than meningocele. It is rare at any level other than the lumbosacral region. The sac is composed of the same elements as in sessile meningocele; the communication between sac and subarachnoid space is generally rather

wide. On occasion the sac may contain only roots of the cauda equina attached lightly to the arachnoidal surface. Most often, though, there will be a meaty, granular area (area medullovasculosa), up to several centimeters in size, on the surface in the midline of the apex of the protrusion, usually its cephalic portion (Fig. 195 A). When small this represents the blunt attachment of the cord to the body surface. When larger it is the dorsal surface of the medullary plate which has failed to fold in and become inclosed in the spinal canal. Such a zone is incompatible with any normal nervous function. It is impractical to attempt to fold over the defect. The prognostic significance is grave as this malformation indicates a stage of developmental inadequacy just short of the hopeless condition of rachischisis (Fig. 195 B).

In the examination of children with sessile meningocele or myelomeningocele, special care must be paid to the following two regions: (1) *Head*—Since hydrocephalus is frequently associated with meningocele, periodic measurements of the circumference, greatest biparietal diameter, and greatest fronto-occipital diameter should be made. At the same time, evaluation of the size and tension of the fontanels should be included. Downward displacement of the eyes in the orbital cavity appears in late stages of the disease. (2) *Caudal part of body*—Inasmuch as the nervous supply of the lower extremities is commonly interrupted whereas that of the upper extremities is seldom affected, the lower part of the body must be studied for evidences of involvement of the cord or peripheral nerves. This study should include inquiry as to the periodicity of evacuation of the bowels and bladder and inspection of the perineum while the baby is crying. A patulous anal sphincter (Fig. 196) with everted mucosa or an uncontrolled bladder bears serious implications. Voluntary movements of the legs and responses to noxious stimuli must be noted as evidence of paralysis and anesthesia. An evaluation of reflexes and sensation is essential. Some have reported difficulty in the differentiation of involuntary movements. Often, when the cord is extensively involved, changes in the skin will be evident (Fig. 197). It must be remembered that mechanical stimulation of the exposed cord in myelomeningocele may produce movements of legs and perineum even though voluntary movement is impossible. The characteristic picture of an infant with lumbosacral meningocele or myelomeningocele, early hydrocephalus, deformed legs devoid of sensation or movement and often held forward at right angles to the body, relaxed perineal structures dribbling urine and feces, and eventual decubitous ulceration, is one which must be recognized as hopeless, difficult as are the implications of such a decision.

Fortunately there are lesser degrees of affliction, some of which offer sufficient hope to justify an attempt at eradication of the chief causative factor. In the selection of these patients the neurological surgeon must put into practice his entire philosophy of life dealing with the relationship of any individual to all of society. He must remember that the degree of improvement in a congenital defective will be small. Beyond this no rule for the selection of patients suitable for operation can be prescribed.

The selection of an optimum time for operation has provoked friendly, though stoutly defended, differences of opinion among neurological surgeons. Some feel that in all cases repair should be accomplished at as early a date as possible; others would postpone all operations until the patients have reached several months or even years of age; as usual, generalization is difficult. Postponement will add to

the ordinary hazard by reason of potential breakdown of the sac or other source of infection. On the other hand, in the occasional patient whose sac is small and well covered, usually a pedunculated meningocele, operation may be delayed, often as late as school age.

Circumstances may exist which bring the entire field cleansed with soap and water, alcohol, and an alcoholic solution of a selected bactericide. At this stage administration of the sedative may be started. In infants up to a few weeks of age, a sugar teat saturated with some alcoholic spirit such as brandy will usually suffice. In older children ether is undoubtedly the



FIG. 196. Patulous anal sphincter in a baby with myelomeningocele.



FIG. 197. Changes in skin associated with lumbosacral anesthesia present in, and poor care afforded, a child with myelomeningocele.

the repair into the field of emergency surgery. These will be discussed in a later section.

OPERATIVE PROCEDURE. The complete eradication of any infection is essential. If the sac is healthy, the baby is placed on the abdomen, preferably lying on a protected hot-water bottle. Every precaution to prevent a drop in temperature is essential. The surrounding skin is shaved and safest drug. It must be remembered that children with congenital defects of the central nervous system are especially prone to die under anesthesia, and the period and depth of narcosis should be kept at an absolute minimum.

In the ensuing procedure (especially in infants), gentleness, intelligent speed, and absolute control of bleeding by hemostatic forceps, ties, and electrocoagulation are es-

sential. The skin is incised just at the horizontal equatorial circumference or, if the thin parchment-like covering extends beyond this, a margin of normal-appearing skin sufficient to allow plastic closure without tension should be allowed (Fig. 198). The incision is carried through the layers tissue down to the opening into the spinal canal. The exact size of this hiatus then can be determined. When it is desirable to strip the epithelium from the dura arachnoid over the dome of the cavity, it should be done at this stage of the operation. The sac is opened and its contents may be
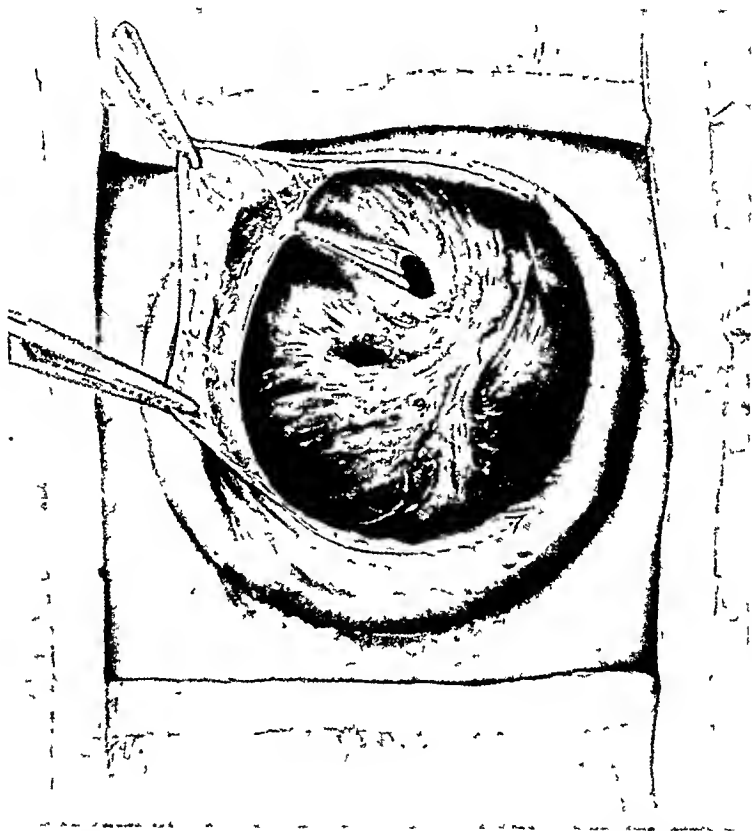


FIG. 198. Incision in skin is made just proximal to parchment covering of dome of sac. Incision is carried through fatty subcutaneous tissue to wall of sac.

of the skin to the meningeal lining of the sac. Care taken not to puncture or rupture the sac too early will be rewarded by the speed and facility with which the procedure may be accomplished.

When the dissection around the circumference of the sac is complete, the meninges are stripped free of the adjacent studied. Nerve filaments are separated from fibrous attachments to the meninges; any attachment of the spinal cord must be interrupted without destruction of functioning tissue. Special care is required in replacing the nerve elements within the spinal canal so that they will be free to move cephalad as growth occurs. Serious

and depressing complications follow the anchoring of the caudal cord with prevention of ascent. Hemostasis must be absolute if any oozing has followed the separation of adhering fibrous bands.

Most neurological surgeons amputate the sac just above the level of the defect in the canal, leaving only sufficient wall for convenience in suturing the edges together. The opening is reinforced by exposing the
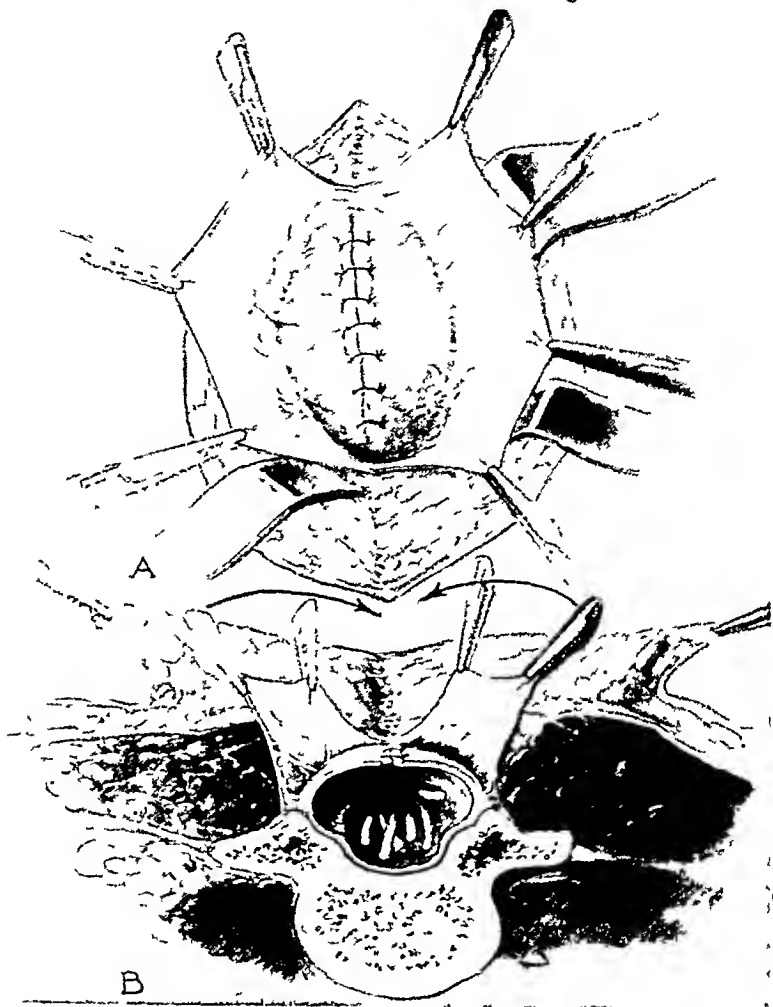


FIG. 199. After removal of sac, its stump is sutured and fascia is stripped from paravertebral muscle for re-enforcement of covering.

It is advantageous to have a stimulating unit at hand to help differentiate nerve roots from bands of connective tissue The stimulation should be done at the center of the exposed nerve so that trauma caused by the patient's sudden jump will be minimal.

lumbar fascia laterally, cutting a portion from each side, and suturing these together over the midline. The subcutaneous tissue and skin are closed tightly. Others, notably Penfield and Cone (1932) believe that the sac of spina bifida plays a part in the absorption of cerebrospinal fluid

and that the incidence of hydrocephalus following repair of meningocele or myelomeningocele can be decreased by preservation of this considerable area for the exit of fluid. Accordingly they save as much of the lining of the sac as possible, rolling it up to its point of emergence from the spinal canal. In any event the defect is best covered by a doubly imbricated tent of fascia from the lumbar region (Figs.

POSTOPERATIVE CARE. After operation, for the first 72 hours at least, the baby is kept lying prone with the head lowered; if possible this position should be retained until the sutures are removed on from the third to the sixth postoperative day. This maneuver reduces pressure on the lines of suture and minimizes the potential danger of leakage of the cerebrospinal fluid; the possibility of contamination of the wound
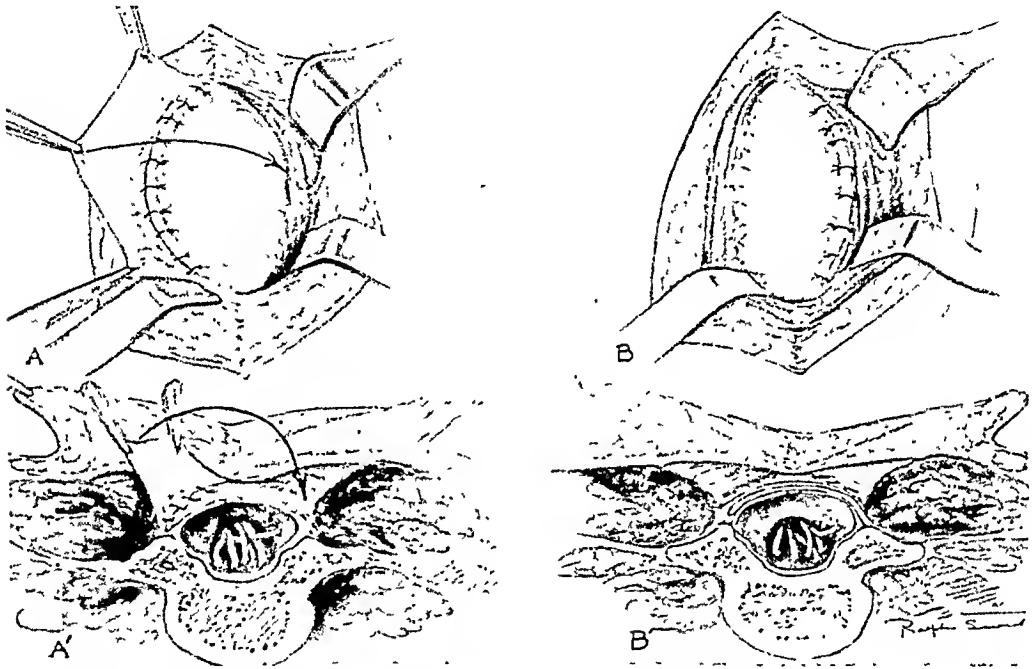


FIG. 200. Fascia from each side is folded to base of opposite side producing a complete double imbrication.

199, 200). The further closure of the wound consists of the approximation of the subcutaneous fascial layer with fine silk, cotton, or steel wire, inverting the knots. The edges of the skin are closed with interrupted sutures of fine silk or cotton. If the defect is large, closure may be difficult, and this aspect must be remembered throughout the procedure. An overly extensive removal of skin may prove to be embarrassing.

by urine or feces is likewise reduced. After the wound has healed, the head is gradually raised to a normal position.

EMERGENCY REPAIR OF MENINGOCELE AND MYELOMENINGOCELE. Not infrequently the sac of meningocele will rupture during the passage of the infant through the birth canal. The surgeon then is confronted with a contaminated wound involving the central nervous system. If no hydrocephalus is noted and if there is evidence of intact

motor and sensory systems indicating satisfactory innervation of the caudal portion of the body, repair becomes an emergency procedure. Under such circumstances special precautions must be taken against the lowering of temperature and loss of blood. In other respects the procedure is as outlined for the elective operation. The newborn stand operations well.

### CONGENITAL DERMAL SINUS

In 1934 Walker and Bucy called attention to a congenital condition nearly always associated with spina bifida and called by them "congenital dermal sinus." The sinus consists of an epithelial tube running from the dorsal surface of the body to or even through the spinal dura. These patients, usually very young children, are generally brought to the physician with signs of meningeal irritation or frank meningitis. The additional findings of a minute sinus in a midline dimple in the skin of the back, and an increase in the spinal-fluid cell count justify the diagnosis.

Surgical Procedure. Except under emergency conditions, operation for congenital dermal sinus should not be attempted while there is any evidence of active infection. Wet dressings and sulfonamide medication by mouth or penicillin parenterally and locally are of value in promoting healing. When no soreness, redness or elevation of temperature results from vigorous massage daily for a week there is reasonable security in proceeding with the operation. An exposure of the spinous process above and below the dimple should be planned. The sinus should be excised in one piece. If granulation tissue lies within the dura, however, it may be necessary to cut across the sinus or at least into it in order to establish the exact interrelationships. Granulations beneath and outside the dura often may be excised completely but at times the surgeon will be forced to content himself with drainage, the bactericides,

and good nursing care. The wound should always be treated as if contaminated, being closed in layers with stainless steel or absorbable sutures. One of the sulfonamides or penicillin should likewise be given during the ten days following the operative procedure.

### CRANIUM BIFIDUM WITH MENINGOCELE AND MENINGO-ENCEPHALOCELE

Like the vertebrae, the bones of the skull may fail to unite, leaving the brain incompletely covered. Defects through which meninges, with or without brain substance, protrude are most common in the occiput and subocciput. The base of such a protrusion may be either pedunculated (Fig. 201) or sessile (Fig. 202). The epidermal covering tends to be complete more often than in the analogous spinal lesion. Cranium bifidum with meningocele or meningo-encephalocele presents problems similar to those already noted in the consideration of the complications of spina bifida. Interference with the passage of cerebrospinal fluid is common and results in hydrocephalus. Considerable proportions of the brain, up to more than one-half, may be contained in the herniation, but not all instances present such hopeless situations. The smaller suboccipital sacs, with or without brain, connected with the cranial cavity by small openings, may be justifiably amputated. Any evidence of hydrocephalus, involvement of the cranial nerves, marked bony defect, or extensive herniation of brain contraindicates operation.

Operative Procedure. As in spina bifida with meningocele, operation *once decided upon* should be carried out at as early an age as possible. The skin being in good condition, the incision is made in a fusiform fashion, sagitally, the necessity of ample skin for closure being constantly borne in mind. The sac is stripped down

to its base by blunt dissection, and is carefully amputated there. In meningo-encephalocele it is usually· wise ˎto ligate the base, since large vessels frequently accompany the extruded brain. Rarely is it feasible to return much of the meninges or brain to the cranial cavity in a case in which operation holds any hope of success. When the stump has been returned to a position within the skull, the osseous defect, if it lies below the level of the nuchal line, may be covered by muscle and fascia. If the defect lies above this line stainless

ploration of an intra-abdominal or pelvic mass. The authors have seen them as part of a pelvic dermoid. Inasmuch as each case of this rare condition presents an individual problem, each situation must be approached on its own merits.

Medullocerebellar Traction Displacement (Arnold-Chiari Malformation). This condition consists of a herniation of the cerebellar tonsils and medulla into the upper cervical canal (Fig. 203); it is caused primarily by abnormal changes in the spinal canal rather than by pressure



FIG. 201. (Left) Pedunculated encephalocele.
FIG. 202. (Right) Sessile encephalocele.

steel wire mesh is well tolerated and reenforces the tissues satisfactorily. The line of suture should lie to one side of the opening in the bone if this is possible.

Anterior Spina Bifida or Anterior Cranium Bifidum with Meningocele. Anterior cranium bifidum with meningocele or meningo-encephalocele is inoperable. Anterior lumbosacral spina bifida with meningocele is exceedingly rare. It may be associated with dorsal spina bifida with or without meningocele. Discovery may be by x-ray, may occur during the repair of a dorsal meningocele, or may result from the ex-

from within the cranium. Any condition preventing normal ascent of the spinal cord within the canal (for example, spina bifida with myelomeningocele or meningocele) may produce this condition. Instances of cryptogenic traction displacement have been recorded.

As the spinal cord is prevented from its normal cephalad migration within the canal, the progressive difference between the length of the cord and that of the canal must be taken up by the caudad traction displacement of the medulla into the upper cervical spinal canal. The tonsils of the

cerebellum are included in this apparent migration because of their anatomic relationship to the medulla. Once started, the process is further advanced and complicated by embarrassment of the circulation bellar traction displacement fall under the headings of (1) hydrocephalus, (2) cerebellar disturbance, (3) irritation and paralysis of cranial or, rarely, spinal nerves, and (4) compression of the medulla and
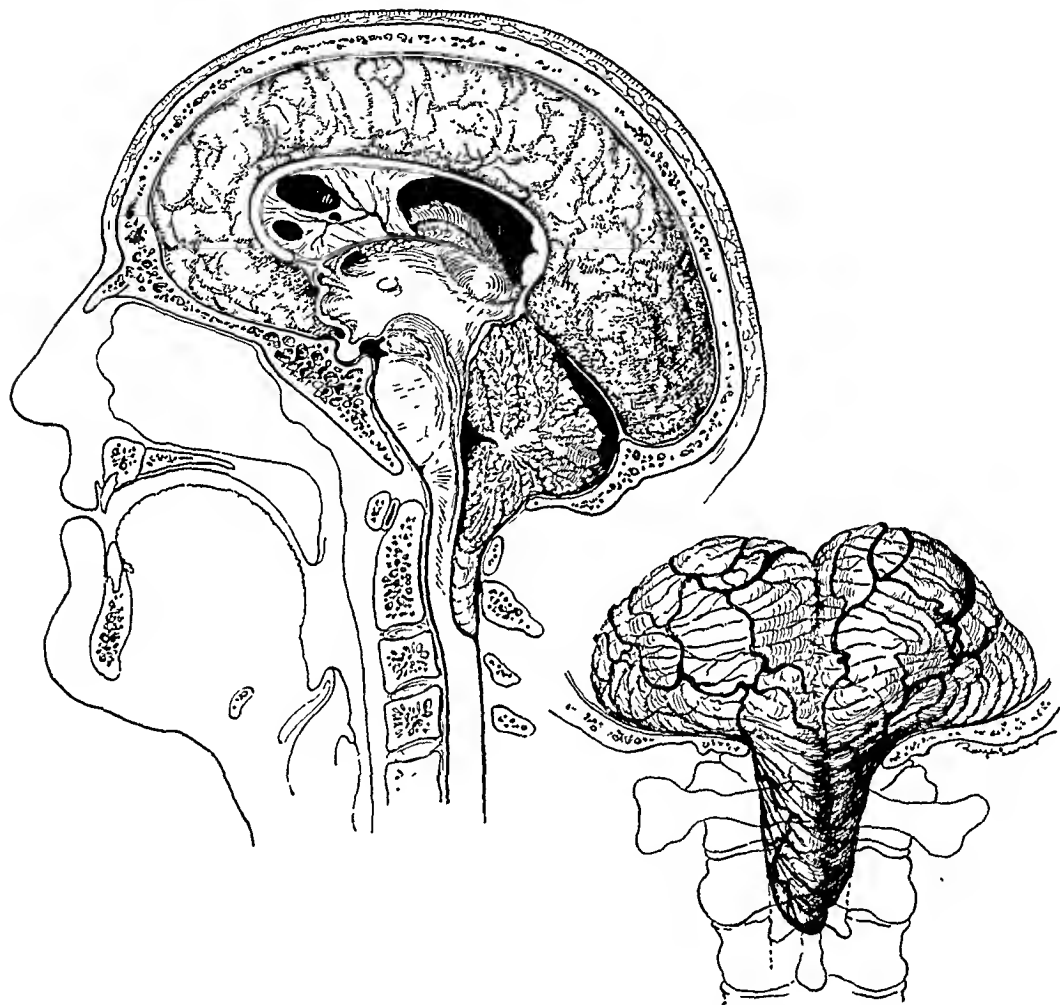


FIG. 203. Pathologic anatomy of medullocerebellar traction-displacement (Arnold-Chiari malformation).

of the cerebrospinal fluid with consequent intracranial hypertension. Hydrocephalus results; a vicious circle is established. The possibility of this complication must be considered in every case of spinal myelomeningocele or meningocele.

The neurologic findings of medullocere- cord by the herniated cerebellar tonsils. The signs are progressive. Usually the patient is still in infancy, yet operation has been performed as late as the third decade.

OPERATIVE PROCEDURE. First the suboccipital region and the laminae of the upper cervical vertebrae are exposed. In most pa-

tients this can be done satisfactorily through an incision from a point just above the occipital protuberance to the spine of the third or fourth cervical vertebra. The suboccipital musculature is cut transversely just below the nuchal line and then elevated subperiosteally to give adequate exposure of the cerebellum. The vertebral laminae are likewise exposed by the subperiosteal elevation of attached muscles, and are removed by means of rongeurs. The dura is opened and separated from the underlying tissue to which it is usually attached by many adhesions. The dural opening must be carried out to a point below the tip of the elongated cerebellar tonsil. The mere opening of the dura and arachnoid may be sufficient to relieve the condition; in the case of infants it will be all that the patient can stand. Some surgeons have resected the cerebellar tonsils and have freed the nerves involved in the displacement. The patients have done so poorly, however, that the procedure is falling into disrepute. After the malformation is decompressed the dura is left open and the muscle, fascia, and skin are closed with interrupted nonabsorbable sutures, care being taken to prevent leakage of cerebrospinal fluid.

### PRIMARY BASILAR IMPRESSION (BASILAR INVAGINATION, PLATYBASIA)

This is a congenital malformation sometimes associated with neurologic abnormalities which may be alleviated surgically. The defect consists of a cephalad bulge of the region of the foramen magnum as if the base of the skull had been softened and allowed to settle. This produces a shortening of the anteroposterior diameter of the foramen magnum and a buckling of the basiocciput and basisphenoid with some flattening of the sphenoid or basal angle, hence the term platybasia. Often associated with this condition are cervical spina bifida as well as distortion of

the cervical laminae and spines and of the occipital bone about the foramen magnum as a result of congenital malunion of the various anlagen of these structures (Fig. 204).

The diagnosis of basilar impression, with or without clinical findings, is made by a lateral x-ray view of the skull. Normally the odontoid process and first cervical vertebra should lie below (caudad to) a straight line drawn from the posterior
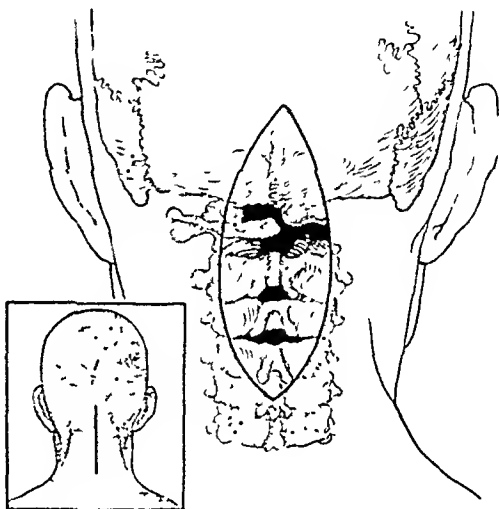


Line of incision.

FIG. 204. Fusion of right arch of atlas to occiput associated with platybasia.

edge of the hard palate to the posterior rim of the foramen magnum. When all or any considerable part of these structures lie above the line, platybasia exists (Figs. 205, 206). A type of secondary basilar impression resulting from generalized disease such as osteomalacia, hydrocephalus, osteitis deformans, dystrophia cleido-cranialis, etc., has been described.

Ebernius classed the neurologic findings on the basis of (1) cerebellar disturbance, (2) compression of the medulla by the odontoid process, (3) irritation and paralysis of cranial and upper spinal nerves, and

(4) increased intracranial pressure. Symptoms most often appear in the second, third, fourth, and fifth decades.

Operative Procedure. Treatment for the neurologic symptoms of basilar impression is operative. Recognition and introduction of this mode of therapy is recent but the results thus far reported are encouraging.

The procedure consists of the subperiosteal exposure of the suboccipital portion of the skull and the spinous processes and laminae of at least the upper three cervical spinal-fluid channels. With all of the exposed structures freed and a ready flow of cerebrospinal fluid established, the dura may or may not be closed, depending on the circumstances in each case. As a rule the advantages of closure are outweighed by its disadvantages. Muscle and skin should be sutured meticulously to avoid a leakage of cerebrospinal fluid, especially if the dura is left open.

Because this operation further weakens



Fig. 205. Roentgenogram showing platybasia. Note dorsal arching of basiocciput and basisphenoid, obtuse angle at level of sphenoid sinus, and projection of atlas and odontoid above a line from palate to posterior border of foramen magnum.

laminae of at least the upper three cervical vertebrae as described in the preceding section. These bones must be removed to an extent sufficient to permit adequate examination of the cerebellar tonsillar region. It is essential to open the dura, which may be thick, and to separate any adhesions between it and underlying structures. The cerebellar tonsils will usually be found herniated into the upper cervical canal. The incision of the dura will relieve this herniation to a great extent but amputation, if possible, may be required to insure proper re-establishment of the cerebro-

a defective spinal axis, fusion with rib or tibial grafts has been recommended. Except under unusual circumstances, however, this added procedure seems to be unnecessary.

### SPONDYLOLISTHESIS

Spondylolisthesis, though primarily an orthopedic problem, may progress to such a degree that changes in the nervous system require neurosurgical treatment. The most commonly reported involvement of the nervous system consists of compression of the cauda equina by the narrowed canal.

resulting in varying degrees of sensory and motor loss in the sacral segments. According to Lewin, the motor symptoms appear early in unilateral spondylolisthesis. In the bilateral lesion, however, the progress is sufficiently slow, as a rule, to allow space for the cauda equina, and a complete root lesion is rare.

In complete spondylolisthesis, caudal displacement of the entire dural sheath in addition to tugging on the filum terminale may superimpose signs and symptoms arising from the upper portion of the cord on the sensory and motor changes more commonly seen in the caudal part of the body (Fig. 207). Sensory changes in the upper
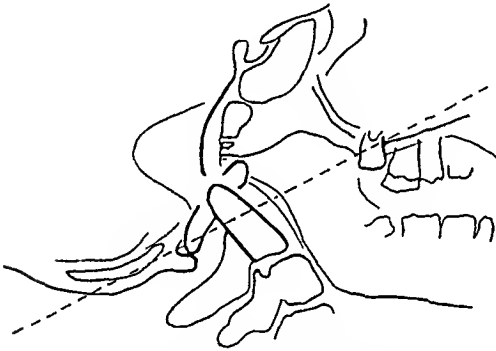


Fig. 206. Diagram of Fig. 205, demonstrating points mentioned there.

extremity, headache, dizziness, and evidence of partial obliteration of the craniocervical subarachnoid space have been observed when the lumbosacral luxation has been extreme. The pathogenesis is similar to that seen in medullocerebellar traction displacement (Arnold-Chiari malformation).

Operative Procedure. The neurosurgical problem in this disease consists of relief of the pressure created by the anterior movement of the vertebral bodies. An equally important consideration, however, is the preservation of a sufficiently intact spine to permit satisfactory stabilization by the orthopedic surgeon.

A complete subperiosteal exposure of the spines and laminae in the affected area must be accomplished. Unilateral laminectomy, preferably on the side of greatest involvement of the nervous system, will allow the stretched dural sheath to rise out of the canal to a position lateral to the base of the spinous processes. Unroofing of any compressing portion of the sacrum may be of additional aid in releasing the caudal sac. The laminectomy must be extended until satisfactory relaxation of dural tension is accomplished. Suitable fusion of the remaining bony elements may then be carried out by the orthopedic surgeon at the same operative procedure.

INJURIES TO SPINAL CORD AND CAUDA EQUINA

When the spinal column is injured, the spinal cord and cauda equina escape damage in a great majority of instances, but when they are not spared the situation presents most serious possibilities, frequently involving permanent paralyses or early death. Though lesser degrees of trauma are compatible with a return to normal function, the range of possible disabilities is vast and varied. Not only do the pathologic changes differ in severity, but the areas affected extend from the lower sacral dermatomes to the occiput. The nervous system does not suffer alone; the bone, ligaments, and cartilages participate. Active and intimate correlation of the knowledge and skills of the orthopedist and the neurologic surgeon is required for the best care of the patient, and decisions as to active treatment or surgical intervention are not always easy.

Discussions on the advisability of laminectomy for patients with injury to the cord provoke frequent debate, though neurological surgeons of wide experience are in substantial agreement on the selection of cases for this operation and on the possibility of accomplishment. The *indications*

for operative therapy are of primary importance rather than the details of technic which are not peculiar to traumatic conditions. For this reason, more than casual attention should be paid to certain fundamentals upon which judgment is based.

The management of the permanently paralyzed unfortunate requires all that is



FIG. 207. Roentgenogram showing extreme spondylolisthesis. This patient had symptoms in the areas supplied by the lumbosacral and high cervical segments.

best in nursing and medical care, unremitting vigilance to prevent bedsores and to give the patient even reasonable comfort, resourcefulness in providing occupation and continued observation for the possible development of infection. When the maximum restoration of injured tracts and nerves has occurred, the ingenuity of the surgeon is taxed to devise the most efficient application of such muscular forces as the patient may command. Transplants of tendons, arthrodeses, braces, splints,

supports, and aids to locomotion demand consideration. Not least is the psychologic management of the handicapped patient and his restoration to useful work. In the early stages after injury his future physical and mental welfare is decided and it is then that care is most time-consuming and exacting.

Closed injuries of the spinal cord present these problems, and, in dealing with wounds from missiles and stabs, a contaminated field is an added danger. Particularly in the treatment of open wounds of the spinal canal, but also to a lesser extent in those produced by indirect violence, trauma to other parts such as blood vessels, chest, abdominal organs, pelvis, and extremities must be considered. These may modify what would be the most desirable treatment if the neurologic condition only were to be considered. Late complications such as increasing deformity of the spine, adhesive arachnitis, and root pains may require operation months or years after injury.

METHOD AND INCIDENCE OF INJURY

An appreciation of the force of the trauma affords some preparation for the severity of the findings. Fracture dislocations of the neck caused by accidents in football and diving are common, and from the crashing or overturning of automobiles and falls from heights are frequent. Injuries at birth, especially during breech deliveries, may cause separation of the cord in the upper thoracic region. Among troops in military service, the closed injuries caused by disasters in jeeps, trucks, and motorcycles are notably frequent. Crumpling of the spine from acute flexion when in a sitting position, or a similar mechanism produced by falls on buttocks or shoulders, or by cave-ins in mines, account for many cases.

Aggravation of the injury or actual production of damage to the cord may occur

when the patient is first moved; this is so frequent as to have prompted national campaigns for instruction in first aid and transportation. When spinal injuries are suspected by reason of pain in the back, paralysis, or loss of sensation, the patient should, in the absence of medical advice, be so handled as not to alter the alignment of the spine until it can be done advisedly.

For removal of the injured from cramped spaces such as airplanes, boats, and mines. or for limited transport, special ingenious splints or stretchers have been devised. The three-foot aluminum splint of Wagoner hyperextends, immobilizes, and supports the head and spine. The stretchers, the origin of which is unknown to the authors, used by the Royal Air Force, are made of a few lengths of bamboo incorporated in canvas. To permit folding over, shorter supplementary lengths are placed in extensions of the canvas corresponding to the arms and legs. These encompass and splint the extremities and hold them firmly. A small pillow and a strap over the forehead fix the head. Canvas straps surround the whole and rope slings are included for handles.

Penetrating wounds involve less extensive damage to bones and ligaments than do closed indirect injuries, though all degrees of trauma to the nervous tissues may occur. Missiles are likely to produce such marked effects. Even without direct contact with the cord, the communicated force may utterly destroy it, and all manner of lesser degrees of injury are seen. Rupture of the posterior longitudinal ligament readily occurs with jackknifing, as do injuries of the intervertebral cartilages and tears of the ligamenta flava. The capsules of the joints and articular facets and the interspinous ligaments are not spared. When violence has been extreme the lower part of the spinal canal may be seen to be completely offset from the portion above, shearing off the entire content.

It has beeen said that, during peacetime, damage to nervous tissues occurs in about 10 per cent of all injuries to the spinal column, and perhaps this is somewhere near the truth, though such figures possibly do not take into account injuries immediately fatal, such as those at the third or fourth cervical vertebra or higher. About 40 per cent of the neurologic injuries are at the twelfth thoracic and first lumbar vertebrae. Cervical injuries are next in frequency. Dislocations, unilateral, but more particularly bilateral, are characteristic of the low cervical area and are most common between the fifth and sixth cervical vertebrae. The persisting displacement may be extreme, as shown by x-ray. The film. however, shows only the position occupied by the vertebra at the instant the view was taken and not the most extreme displacement at the moment of injury. No damage to the cord may occur, or such damage may be complete, even without roentgen evidence of injury to the bone.

Browder and Grimes found that 16 of 88 patients with injury to the cervical cord showed no demonstrable lesion of the bone. Such a lack of visual evidence is less frequent elsewhere in the spine. Injuries of the higher cervical vertebrae are seen less often. Very likely many of those occurring above the level of phrenic innervation are immediately fatal. Somewhat more numerous are the forward displacements of the atlas and axis following fracture of the odontoid process or tears of its ligaments.

Compression fractures of the upper thoracic vertebrae, sometimes associated with the fractures of the os calcis, occur when the patient falls on his feet from a height; fractures of lower thoracic vertebrae are most likely to result from falls on the buttocks or other forced flexions. They are said to have occurred (usually between the fourth and tenth thoracic vertebrae) in 43 per cent of patients having convulsions from metrazol therapy.

spinal shock may be present when the cord is not divided, but only sufficiently injured to cause a complete, though temporary, interruption of the conduction of all impulses through the injured portion. We speak of all such patients as showing "evidence of a complete lesion" until there is some conduction of impulses from above. In repeated examinations of patients with lesions first diagnosed as complete it will be found that some will give evidence of returning sensation (in the anogenital region particularly) or possibly motion, indicating that the interruption was in part physiologic rather than anatomic. Such patients are then reclassified as having incomplete lesions.

In a third group of patients it may be evident from the time of accident that the lesion is incomplete. These show retention of some movement, or voluntary movement may be lost, while some sensation remains, sometimes persisting only in the lowermost sacral segments, perineum, or lower extremities. Deep painful sensations may be present when other forms are lost. It is useful to cause immediate forcible distortion or flexion of the toe without the knowledge of the patient, at the same time asking if any sensation is felt. If this maneuver is not recognized it may be assumed that pain, temperature, touch, and deep sensibilities are lost. If, however, some sensation is felt, a sensory chart should be made in detail for later comparison. Brown-Séquard lesions, more or less typical, are not uncommon, particularly in cervical injuries, and are often associated with damage to the brachial plexus and to the sympathetic nerves. In these cases pain and paresthesia may be permanently distressing. In incomplete lesions further recovery is slow. It continues often over months or even years and not infrequently is surprisingly great.

Next in the examination the upper level of sensory loss should be noted so that a rise in this level may be recognized promptly. A band of partial loss or hyperesthesia will lie just above the region of total loss. Differences in temperature of the two sides of the body indicate vasomotor paralyses. Vasomotor failure with elevated temperature on the surface is common with cervical fracture dislocations.

The neurologic chart is invaluable since it permits an appraisal of alterations in findings in lesions that are partial but are changing in severity, allowing a decision on the advisability of operation or other treatment.

In complete lesions the segmental level of the injury to the cord is readily apparent. The somatic representation of a few levels may easily be kept in mind and will make the site of the commoner injuries obvious without reference to neurologic charts. The innervation of the deltoid and biceps muscles comes from the fifth cervical segment; Horner's syndrome appears with injury to the first or second thoracic; lesions between the fourth cervical and second thoracic segments produce a sensory level at about the junction of the manubrium and the sternum. The intercostal levels are obvious. A sensory level at the ensiform indicates a lesion at the sixth thoracic segment; one at the umbilicus, the tenth thoracic. The area supplied by the twelfth thoracic nerve is midway between the umbilicus and the pubis and the knee jerks are innervated by the third lumbar. These major neurologic landmarks serve to give a rough localization.

Injuries to the lumbar area may involve the cauda equina below the tip of the conus which lies at the lower margin of the first lumbar body or, at the dorsolumbar junction, may involve the lowermost segments of the cord as well. At this level the nerve passing from the cord to the intervertebral foramina of exit have an oblique course so that a transverse lesion of the dural canal may involve either the cord

or the nerves independently, or both, the neurologic picture showing corresponding variations in the level affected. Lower, opposite and below the level of the second lumbar vertebra, the involvement of filaments of the cauda equina may be partial, as is common, or complete, depending upon the character of the bony injury. The sensory, motor, and reflex manifestations will alter correspondingly.

## SURGICAL EXAMINATION

Many patients with cervical trauma have concomitant head injuries and Coleman has called attention to the frequent combination of cranial and cervical clavicular (or shoulder-girdle) injuries.

After jackknifing, lower levels of spinal injury may show kyphos. There may be pain, tenderness, spasm, and collections of blood and spinal fluid. Mobility and altered spacing of spinous tips may be noted. In the neck voluntary motion without pain may be present even in the presence of severe fracture dislocation.

Lumbar puncture and determination of a spinal block (Queckenstedt test) are essential in partial (incomplete) lesions in which continuing or alternating degrees of pressure may be of importance.

Diagnostic roentgenographic studies should be requested as soon as the patient's condition permits. Handling of the patient, with maintenance of correct position, must be done carefully; altering the position of the tube rather than that of the patient is desirable. The views which are especially informative vary with the region in question. Anteroposterior and lateral views are always required. In injuries to the axis and atlas additional views through the open mouth are valuable. In lesions of the lower cervical region anteroposterior views may show split bodies, fractures of the lateral masses, and altered spacing of the spinous tips, while in the lateral projections are seen fractures of

the spinous processes. In examining the laminae and articular facets, if the line of the rays is 5 or 10° off the direct lateral position, the right can be differentiated from the left. At 45° the intervertebral foramina and pedicles are seen. In examination of the thoracic spine anteroposterior and lateral views are of principal assistance; complete displacement with a shearing off of the entire canal may be seen. Oblique views are likely to be confusing. For the lumbar spine, anteroposterior, lateral, and 45° films are taken, and the erect position is helpful in examining patients with old injuries and those who are ambulant. For sacral and coccygeal injuries, anteroposterior and lateral films should be taken after the bowel has been thoroughly cleared. To show cleft-like fissured fractures of the sacrum a number of films may be required to permit penetration of rays in the direction of the cleft. Fractures of the pelvic ring are often found in association with them. Tomography or laminography has its place in special injuries. Studies before and after traction show the alterations produced and sometimes make clear the fractures which previously could not be interpreted.

Following the demonstration of complete block in the spinal canal, Coleman advocates the withdrawal of fluid and introduction of air. The exact level of block may then be shown by x-ray. If decompression is performed incision of the dura will demonstrate free fluid above the block or air below it, and relief of the block can be seen.

## SURGICAL MANAGEMENT

The earliest treatment is to place the patient on an air or innerspring type of mattress to equalize and distribute pressure and to remove weight from the areas most likely to be rendered ischemic and to develop decubitus. The knees are partially flexed and support is placed beneath

thighs, knees, and calves, leaving the heels free of any pressure and the soles supported to prevent footdrop. A shift of position at least every two hours is essential. A cradle should take the weight of the bedclothes and tidal drainage of the bladder should be instituted. A dry, smooth bed and meticulous care of the skin by rubbing and the use of alcohol and camphor will be repaid by avoidance of the time-consuming care and dressings which are needed when sloughs have appeared.

The management of the bladder is of immediate importance to the patient's future. Except for a small minority those who survive severe injury to the cord for ten days or two weeks die later of infection to the urinary tract or of sepsis from decubitus.

For urinary retention, catheterization either intermittently or by indwelling catheters, emptying of the filled bladder by manual compression, and cystostomy have been used. Catheterization leads to infection; the trauma plus the inability to free the urethra of organisms and the obstruction make contamination and infection almost immediate. This deserves emphasis, for commonly catheterization for two or three days is practiced prior to the installation of better methods, and in this time the harm is done.

The choice of the immediate method of drainage of the bladder depends on the outlook—whether the injury is complete or incomplete, severe or slight—as well as on the circumstances of environment, personnel, facilities, and requirements of transportation. Previously normal bladders, even though enormously overfilled, rarely if ever rupture. When in such a state, careful, well-distributed manual compression initiates some overflow. Browder and Grimes found the only dangers of the method to occur in elderly patients with thin vesical musculature, possible diverticulae of the bladder, or urethral obstruction from a large prostate. Only three such ruptures occurred in a large series.

An emergency procedure seldom employed, but useful if not relied upon for repetition, is careful sterilization of the skin and direct puncture of the bladder with a fine spinal-puncture needle. With a bladder distended to the umbilicus this may be done two or three fingerbreadths above the pubis in the midline.

Complete emptying of the bladder after great distention should not be immediate for fear of suppression of renal function or of hemorrhage.

For later management two methods have most support: "tidal" drainage, as advocated by Munro, and suprapubic cystostomy. The former is not suitable for emergency use, as in a busy field or evacuation hospital, or for transport. Considerable apparatus is required, and the attendants must be trained in its intelligent use, sterilization, and correct sizes of tubing, or alterations which vitiate the usefulness of the method will creep in. Occasional cystometrograms are desirable. In base hospitals and under civilian conditions it has a most valuable field of usefulness (Fig. 208). Too often, however, Munro's directions are not carefully followed, and the changing of personnel militates against accomplishment of the best results. Munro reports a lessening of infections in the genito-urinary tract from 72 to 14 per cent by the use of this method. Since his report the advent of chemotherapy is an added help. The method is highly commended by those familiar with its correct use.

Early suprapubic cystostomy has many advocates, such as Riches, and it has its advantages. High suprapubic drainage at a point midway between the pubis and umbilicus, performed when the bladder is well distended, will not enter the peritoneal cavity, does not result in a scar fastened to the pubis, is above the most cellular por-

tion of the space of Retzius, does not favor a contracted bladder, and, with the catheter taking an oblique course, permits no significant leakage. With the catheter inter-



1000cc Container

30cm Clamp

Dropper

Air vent or manometer strapped to stand

70cm

100cm

20cm

Apex of siphon curve

Intra-vesical pressure

Mark corresponding to level of pubis

Siphon exit and T tube upside-down

To bladder connection

T tube on end

5mm

6mm

No9 cork

3mm Tubing

3mm tubing with fused end

Reservoir strapped to stand

MUNRO'S APPARATUS FOR TIDAL DRAINAGE

Waste bottle

FIG. 208. Munro's apparatus for tidal drainage.

mittently unplugged, the bladder may be emptied at regular intervals. Transportation is not difficult. The method is not altogether fool-proof and experience has shown that, without suitable attention, leakage and infection will occur. The tidal

drainage of Munro can be connected to a suprapubic catheter when environment permits and is compatible with the establishment of an automatic bladder.

The aims of treatment of the bladder, as expressed by Munro, are to permit drainage, to prevent infection and undue permanent contraction of the bladder, and, finally, to establish automatic emptying. Severe disturbances of urinary function, even though they may not be permanent, have, if not intelligently treated, the most serious potentialities. Sepsis impairs recovery of the cord and is often the cause of death.

General Considerations. Surgical procedures vary with the region involved and must take into account the treatment of the skeletal as well as the neurologic condition. Injuries to the cervical and thoracic portions of the cord and trauma to the cauda present their special features, but some generalizations may be made. It is clear that in the cord no regeneration is possible. Areas damaged but not destroyed resume function as evidences of the contusion disappear. The damage occurs in the cord at the instant of impact, as it does in the brain in cases of depressed fracture. It does not result from continuing pressure, although this may be present from bone or a disorganized intervertebral disk. The resulting paralysis, therefore, is not from continuing compression such as is seen in tumors of the cord. Lack of appreciation of this difference leads to many ill-advised and futile laminectomies. Only a small minority of injuries to the cord are benefited by laminectomy, though surgical treatment to restore the alignment of the spine, reduce dislocations, or fuse weakened portions often are indicated. The aim of the neurological surgeon is to minimize the harm already done, prevent further injury, and restore the patient to as useful a condition as his neurologic condition permits.
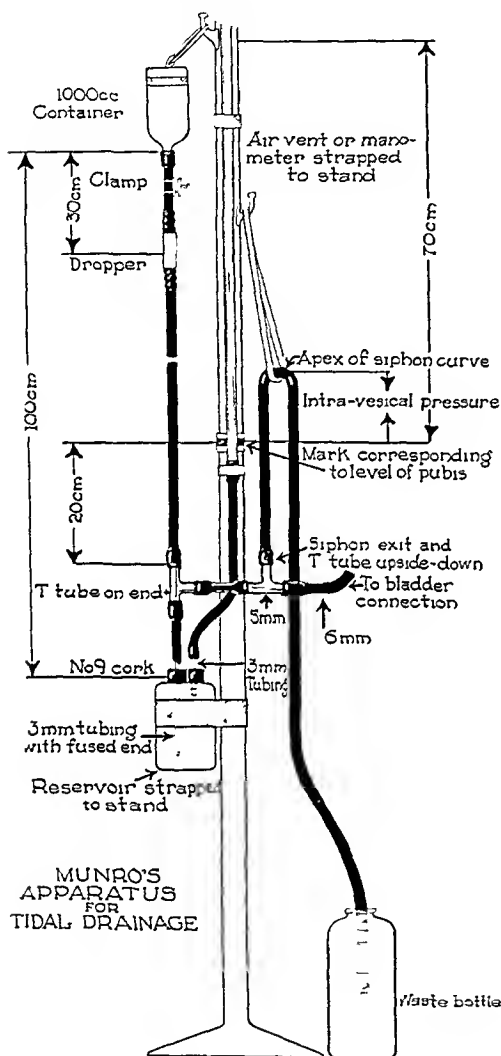
Indications for Laminectomy in Treatment of Closed Injuries. The indications for the operative treatment of cord injury have been provocative of much argument. In general, the more experienced the surgeon, the fewer the cases that will be judged suitable for operation. Operation for complete lesions is futile. When the paralysis has been immediate and complete it will be permanent. In the absence of information that the paralysis was immediate, if signs of a complete lesion persist for 48 hours, it may be assumed to be permanent. Jefferson wisely notes that he has never seen recovery after injury if the sensory loss has been complete. Motor loss without complete sensory loss is no criterion of destruction of the pyramidal tracts. Such a finding—viz., complete motor loss with incomplete sensory loss—is frequently seen with tumors of the spinal cord.

The advisability of operation on incomplete lesions depends on several factors. If fragmented laminae and spinous processes are present, they should be removed. Incomplete lesions which show progressing neurologic involvement should be explored. Incomplete lesions associated with a block after reduction of the fracture or dislocation and immobilization should be operated upon. Intolerable pain may at times be a factor in deciding upon operation. When indicated the operation should be performed as early as the general condition of the patient permits.

On the other hand, a positive Queckenstedt test alone, in the absence of other indications, does not warrant a laminectomy. It is significant that improvement in the neurologic findings may be seen during the persistence of a block. A swollen cord may fill the dural canal and yet function. From experimental work Allen made a tentative conclusion that longitudinal incision and splitting of the cord over one or two segments would, in trauma of certain degrees of severity, permit recovery which otherwise would be lacking. Clinical experience, however, has not afforded support to this view, though it is not certain that it has been given a sufficiently extensive or thorough trial.

Open operation may be indicated to unlock overriding facets and dislocations which have not been reduced by traction and closed methods, or in the presence of loose fragments. Root pains or an increase in paralysis may constitute a trying problem and require removal of bone or cartilage or rhizotomy, even long after injury. In operating, the possibility must be borne in mind that unsuspected loose fragments of laminae or spinous processes may be dislodged.

For cervical fracture dislocation, the unlocking of overriding facets and the restoration of normal alignment and the patency of the spinal canal are urgent in cases of incomplete paralysis and are to be desired in all. Traction by means of head halter and weights or traction with manipulation, after the method of Alfred Taylor or others, may be used. The former is painful, inefficient, and usually unsatisfactory alike to patient and surgeon. Careful manipulation with head traction, reduction of the deformity, and application of a cast is more satisfactory but only in experienced hands. Stookey recommends a position with the head hanging over the end of the mattress and, for hyperextension of the thoracic and lumbar spine, a bolster under the injured area with elevation of the head of the bed.

Of recent years, however, skeletal traction has proved more efficient, reliable and safe. Traction is applied directly to the skull by the use of tongs or wires passed through small adjacent openings. Of the tongs, those devised by Crutchfield, if properly introduced and cared for, have the advantages of ease of application and of permitting the patient to be turned on his side without interference.

Crutchfield gives the following directions for application of the tongs: The area of scalp is shaved and prepared. For correct placement of the tongs, lines are painted on the scalp (Fig. 209) to indicate the midline of the skull and the approximate plane are made down to the skull. The point of the drill is forced in to a depth of 3 mm. in children and 4 mm. in adults. The fixed guard prevents excessive penetration. The points of the tongs are fitted into the perforations in the bone and are held in
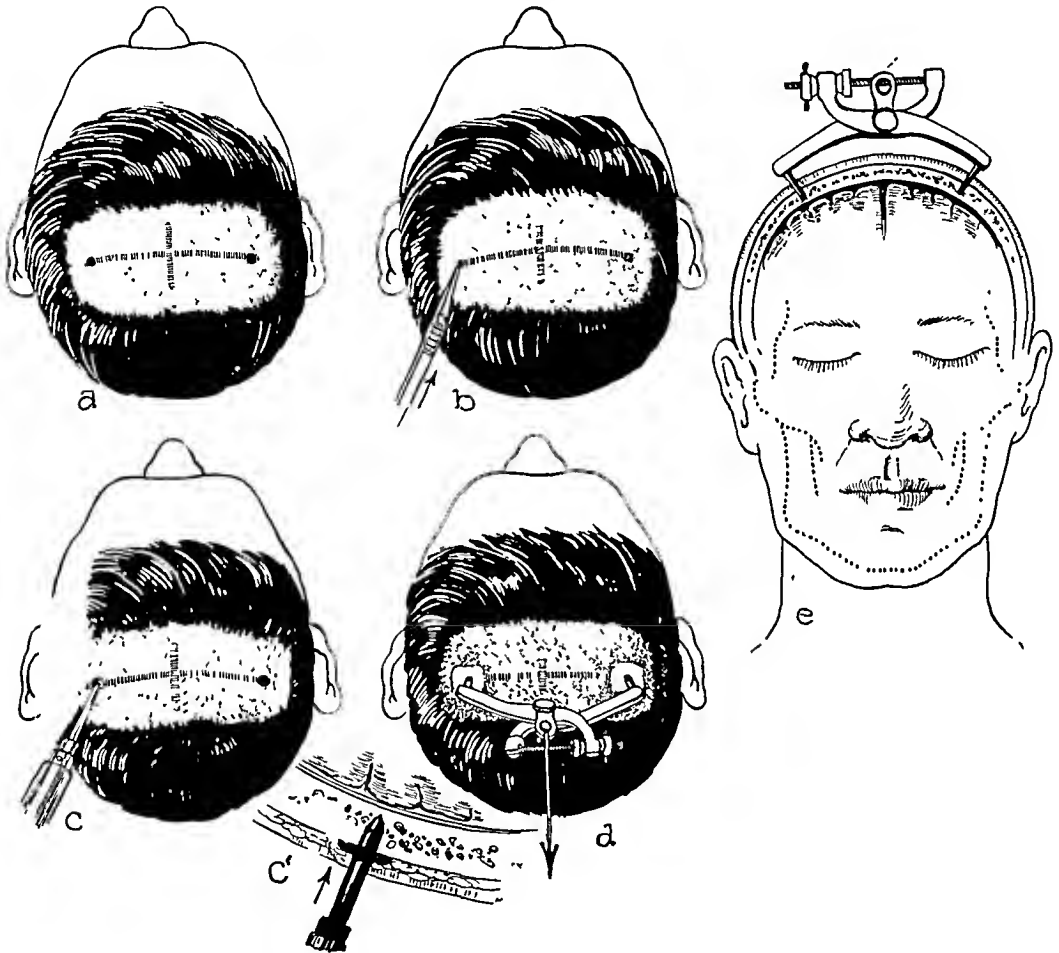


FIG. 209. Details of application of Crutchfield tongs.

of the cervical articulations (above the mastoid tips). With the traction bar resting on the midline the points of the tongs are brought down upon the transverse line. These points of contact are marked for the placement of stab wounds. After injection of novocaine (1 per cent), stab wounds just large enough to admit the drill guard position until the tongs have been locked. Dressings are applied as illustrated and left in place until the instrument is removed. It is very important not to insert the points too close together, as the tongs cannot be tightened. The apparatus for traction is of simple construction and does not hinder the routine care of the patient.

Countertraction is exerted by elevation of the head of the bed. The patient may be turned to either side while traction is in force (Fig. 210). Change of position not only adds to his comfort, but is necessary for the prevention of pressure sores, especially when the sensory loss is marked. When applied correctly and tightened daily, especially during the first few days, the tongs will not pull out. The skull should not be drilled blindly except when using a drill point with a fixed guard. In the authors' Clinic a movable rest for the

weeks. Because of the risk of a recurrence of the dislocation, traction for three or four weeks is the rule and this is followed by the use of a brace or cast. Even then fusion may be required. Traction of 25 or 30 pounds is ordinarily used, and this may be lessened when reduction is accomplished. Much heavier traction has been used for short periods in old dislocations. If fusion is not performed the brace or cast should be worn for five or six months, or even longer.

If tongs are not available, stainless-steel
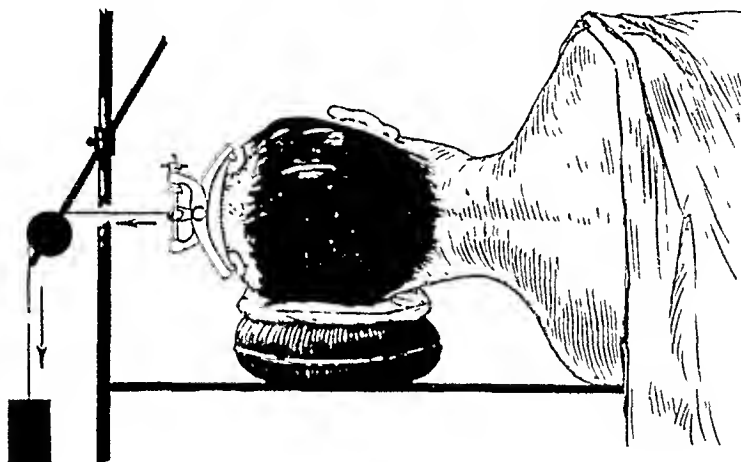


Fig. 210. Crutchfield tongs in place with patient turned on his side.

head instead of a pillow has been added. For traction to act effectively on the cervical vertebrae, the head should be free to be drawn away from the body which acts as countertraction. The weight of the head resting on the bed may interfere to some extent. To overcome this the pillow for the head may be of sponge rubber incorporated in a frame on rollers which rests on a small platform or track so that the friction of the head against the bed is eliminated (Figs. 211, 212, 213).

Crutchfield tongs, if improperly inserted and not regularly tightened, may pull out. When properly adjusted they have been left in place for a considerable number of

wire may be passed through small neighboring burr openings in the skull and out throughout the scalp, to be used for traction. After shaving and preparation of the scalp, a large welt is produced by injecting between the scalp and the bone, 0.5 per cent procaine with 3 drops of adrenalin to the ounce. A short curved incision permits a small flap of scalp to be turned back. With perforator and burrs, two holes are placed about 3 cm. apart. The dura is freed from the bone with a curved separator and the wire is guided through. Its ends are passed through the flap in the scalp and the scalp is closed. Small cotton dressings surround the points of penetration and are
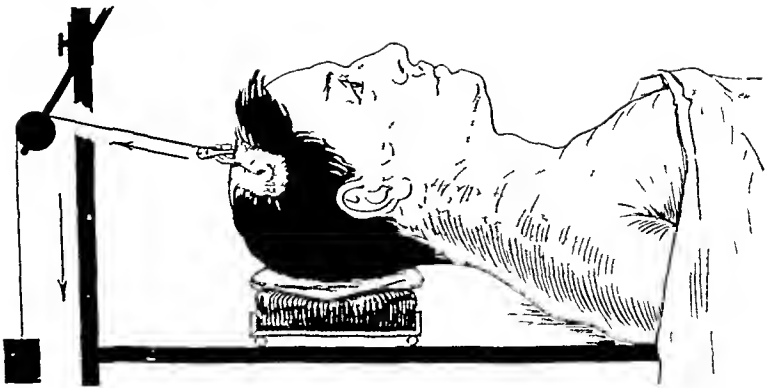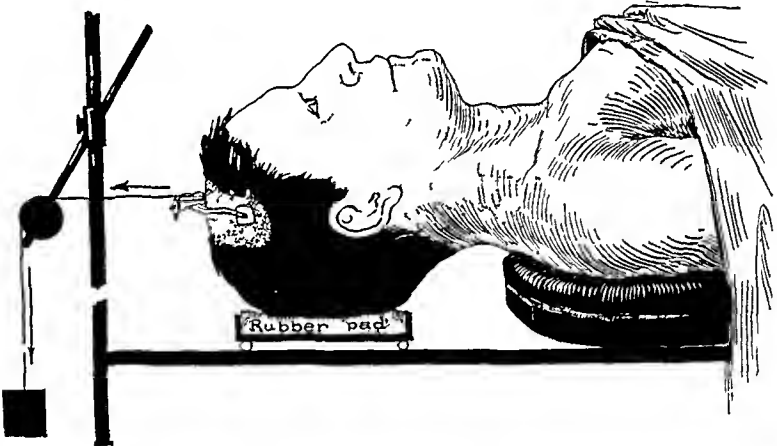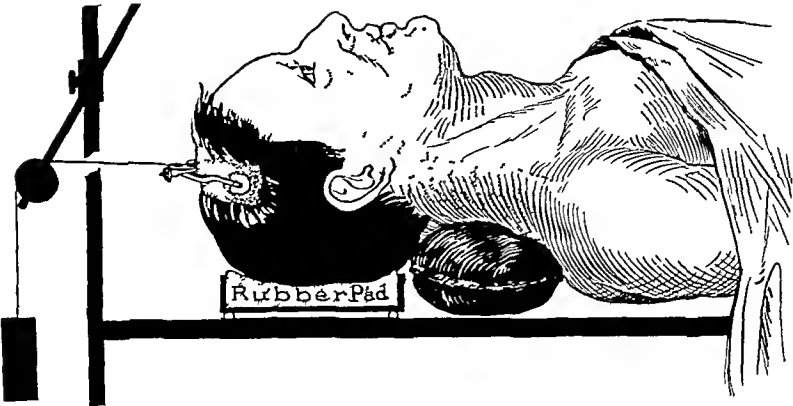
FIGS. 211, 212, 213. Crutchfield tongs applied; movable head rest and direction of traction.

sealed with some impervious material. A similar arrangement is followed on the opposite side. Traction is applied to these wire loops (Fig. 214).

Orthopedic Considerations. Dislocations of the cervical vertebrae are likely to

out the performance of fusion, it is our custom to advise hyperextension and rest in bed for six months. In selected cases, fusion or arthrodeses of the facets may be performed.

In general, conservative orthopedic opin-
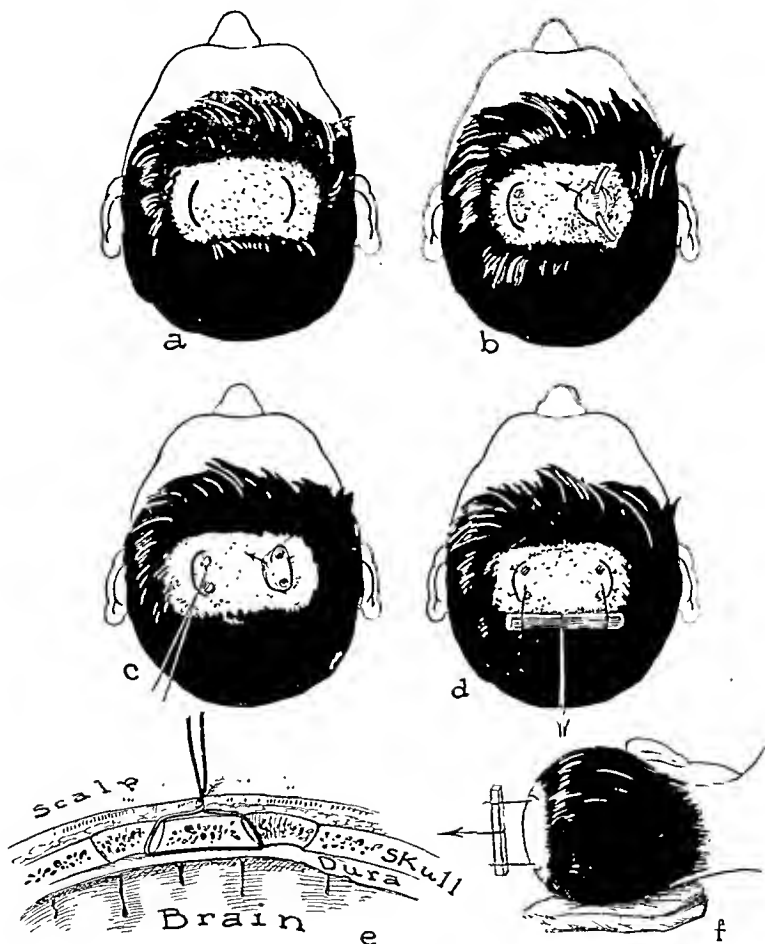


FIG. 214. Arrangement of traction with wires.

recur after reduction even though it be maintained for a considerable time. Fusion is indicated, especially if laminectomy has been performed. Various types of grafts and wirings have been devised for both high and low cervical dislocations.

After laminectomy for thoracic and thoracolumbar compression fractures, with-

ion holds that, in thoracic and lumbar compression fractures without injury to the cord, reduction should be followed by recumbency for from seven to ten weeks. When the patient becomes ambulatory, a brace to support the spine in extension should be worn for at least six months. After laminectomy, if the patient has suf-

ficient neurologic recovery to warrant it, some type of fusion may be indicated. In all patients continued exercises for the

is required, the removal of bone and of intact laminal facets and articulations should be minimal. Taylor reported dislocation



FIG. 215. Cervical traction for the ambulatory patient and to permit traction during operation.

maximum development of the erector spinae group of muscles are essential.

In a structurally weakened spine, the removal of bone which has any function is of course undesirable, and, when laminectomy

and deformity of the cervical vertebrae following bilateral laminectomy and similar experiences have been noted by Adson and Ghormley and Craig and Sheldon.

Late increases in deformity with com-

pression of the cord and pain are not infrequent after fractures, and Horwitz reported that deformities may appear or pre-existing ones be aggravated after lumbar or thoracic bilateral laminectomy. Such experiences indicate the advisability of fusions and support. In the spine already weakened by trauma such procedures become more urgent than when the laminectomy has been performed for a nontraumatic condition. Certain late occurrences tax the combined ingenuity of the neuro-

devised by one of us gives most satisfactory fixation by eliminating the movement of the neck which is present when the temporomandibular joint moves in eating and talking.

**Operative Technic.** The method of laminectomy has been outlined previously After injuries to the cord particular attention should be given to the protection of all bony prominences from pressure during the operation, as irreparable damage to the soft tissues may occur very promptly and



FIG. 216. Boldrey splint for immobilization of the neck.

logical surgeon and the orthopedic surgeon. Such are the progressing paralyses and deformities following bilateral dislocation of the atlas on the axis and displacements after fracture of the odontoid For these conditions replacement and bone graft or decompression with fixation must be sought.

Drs. Frederic Bost, Bret Smart, and Richard Lambert, of the University of California Clinic, devised an apparatus (Fig. 215) which affords fixation, measured traction, and ambulation. If laminectomy is required, it may be performed with the apparatus in place. The brace (Fig 216)

a large slough be the result. Traction on the neck by 'halter or tongs may be advisable before exposure of the cervical laminae is begun. Extreme care must be exercised in the separation of the muscles from loose spinous processes or laminae. When the injury has been recent, greatly swollen or pulped cord may extrude from a dural opening.

Coleman recommends that, with complete blockage of the canal, the spinal fluid should be replaced by air at lumbar puncture. At open operation the site of obstruction and its release are then readily demonstrated.

## CAUDA EQUINA

The cauda equina has greater potentialities for recovery than the spinal canal, as the motor roots may show regeneration if damaged severely, though not if divided. Theoretically, suture is possible, but identification of corresponding roots and approximation are rarely feasible. It is conceivable that a sharply incised wound might permit such repair. Partial injuries of the cauda are fairly common in association with lumbar fractures and locked dislocations. As noted elsewhere, reduction may require open operation and even then retention of the position is difficult. We have been impressed by the degree of spontaneous recovery in this group when the cauda was presumably moderately contused.

As in other injuries, the removal of bony fragments, clots, and foreign bodies reduces the factors that make for an impenetrable scar and constitutes the greatest accomplishment.

## PENETRATING WOUNDS OF SPINE

Open wounds and penetration by missiles or stabs present all the problems of injury to the soft tissues and compound fractures combined with those of the nervous system. Most common under conditions of war, they are of the utmost gravity and are grouped among those to be given precedence for operation. Muscles and indriven fragments of bone produce signs proportionate to the damage they inflicted at the time of injury rather than by continuing pressure. Removal is indicated only because of contamination, to minimize contraction and distortion of fibrous scar and to permit maximal resolution.

In war wounds of the spine the greater length of time between injury and definitive treatment and the associated injuries of head, thorax, and abdomen play a large part in determining survival, and both the immediate and the early mortality are high. Treatment for shock is needed much more often than in the case of closed injuries.

Holmes and Sargent studied 243 cases of gunshot wounds of the spine, followed either to a termination or up to a survival time of six years, and found that the greatest number of survivors were wounded at levels between the seventh and ninth thoracic segments. Later survival depends more upon the severity of the medullary injury than upon its location. The wounds of associated parts and the presence or absence of shock largely determine the treatment. Dural penetration and leakage of cerebrospinal fluid require dural closure in addition to débridement of the soft tissues. As in cases of cranial penetration, sulfadiazine given with alkalis is useful for both prophylaxis against infection and its treatment if established. Local and systemic penicillin has also proved to be of value in allaying infection by susceptible organisms. Single penetration by a small missile, treated early, may require no more than excision of the wound of entrance and neighboring tissues, without disturbance of the missile. Extensive wounds of soft tissues with or without fragmentation of bone necessitate thorough trimming of the wound which is left open and packed loosely to its depth with petrolatum gauze.

When the neurologic findings are caused by concussion of the cord and the dura has not been penetrated, it should not be opened. When the dura has been penetrated and is leaking, some enlargement of the dural wound for cleansing of the area may be advisable followed by closure with fine silk or cotton or by tissue transplant or fibrin film if not otherwise possible. Chemotherapy then is pushed.

**Technic.** This is as for laminectomy in closed injuries save that, in the actual operative procedure, the preparation is by the use of fat solvents and mechanical

cleansing of the skin, while the wound is lightly packed with sterile gauze. General principles apply: limited trimming of the skin to remove devitalized margins with no unnecessary sacrifice, removal of débris and areas deprived of circulation. smoothing of the edges of bone, and light but not snug packing with petrolatum gauze. There is no convincing evidence that the local use of sulfonamides will reduce the number of wound infections or promote the healing of wounds, but general sepsis is apparently less frequent when they are administered. The effectiveness of penicillin, on the other hand, seems well established within its limitations. As for wounds of other parts, a booster dose of tetanus toxoid or tetanus antitoxin is given. A wound in soft tissue down to the dura may require drainage.

## INTERVERTEBRAL DISK
## SYNDROME

In recent years the syndrome of the protruded intervertebral disk has become recognized as a major clinical entity, the treatment of which falls within the scope of neurological surgery. Currently it is of particular importance in the fields of industrial and military medicine.

This syndrome involves the third and fourth lumbar and the lumbosacral disks in by far the majority of cases; hence the initial discussion will be concerned more particularly with this region. Hypertrophy of the ligamentum flavum, closely related to the intervertebral disk syndrome, affects the same level and is included in this discussion. A consideration of the syndrome in the cervical region is reserved for a later section.

**Anatomic and Pathologic Considerations.** The intervertebral disks are semi-elastic plates which lie between adjacent pairs of vertebral bodies. They are thickest in the lumbar and lumbosacral interspaces and thinnest in the thoracic region.

Each is composed of three chief elements, the proportions and physical characteristics of which vary widely. The vertebral surfaces of the disk are lined by slightly concave *plates of hyaline cartilage* which are attached rather insecurely to the spongy bone of the bodies but which are more firmly anchored at their anterior and lateral edges to the bony epiphyseal ring. At these anterior and lateral edges, and to a less degree posteriorly, the cartilages become more fibrous in character and merge into the *annulus fibrosus*, a heavy fibrous and fibrocartilaginous ring, broader in front and gradually becoming thinner toward its posterior edge next to the spinal canal. It is strengthened anteriorly by expansion of the powerful anterior longitudinal ligament. The posterior longitudinal ligament offers poorer support, however, and is even deficient at the disk in a considerable number of instances. Between the cartilaginous plates and contained within the ring of the annulus is the *nucleus pulposus*. Normally this is a resilient cushion of moist mucoid notochordal remnant, fibrocartilage, and connective tissue (Fig. 217).

In later life these structures undergo changes which bear a relationship to the disk syndrome. One type of degenerative alteration may begin as early as the second or third decade when progressive nuclear swelling and encroachment in the annulus appear, contributing to a state of advancing fragility and inelasticity. Areas of pigmented fibrillary degeneration ("brown degeneration") may be present, further weakening the annulus, particularly its posterior aspect where it is narrowest and least rugged. These areas of cellular dissolution facilitate tears in the annulus and permit the backward displacement of nucleus puposus tissue into the spinal canal itself. There the material takes a position, usually toward the side of the canal and

the spinal canal irritates the adjacent root the signs of the disk syndrome appear (Fig. 221). At operation small bits of stringy material may adhere to the curetting instrument, but there is nothing comparable in size to the surgeon's preoperative conception of the true mass present. The annular wall overlying the protrusion will of the joint and lies in close proximity with the root as it leaves the· spinal canal. Inman has shown that this ligament, when overstretched, becomes detached from the upper lamina, the elastic fibers curling up and thickening the structure near the inferior arch. When torn the yellow elastic tissue is replaced by white fibrous scar. In
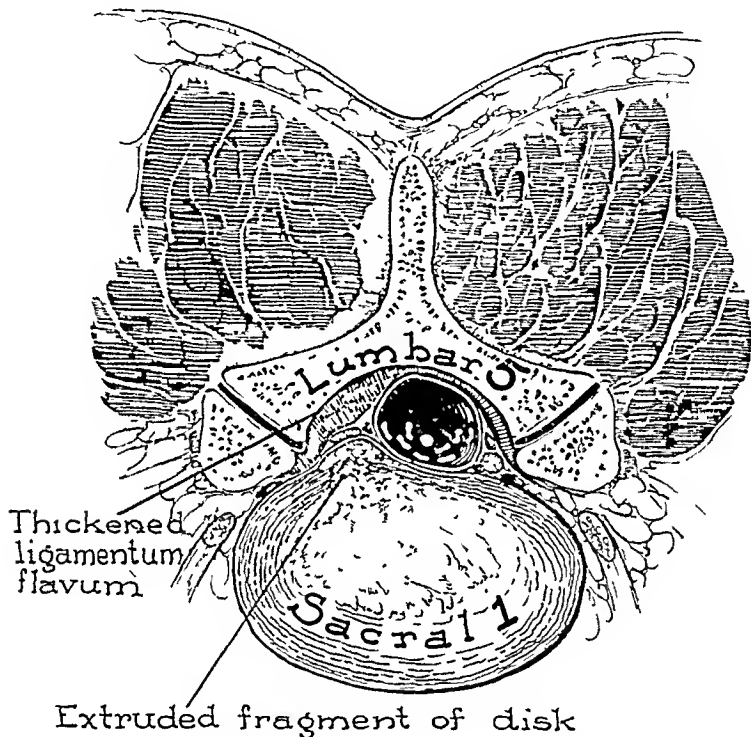


FIG. 218. Same level as Fig. 217, showing extruded piece of cartilage and nucleus pressing first sacral root against a thickened ligamentum flavum.

probably be thicker than is the case with a herniated nucleus pulposus.

Associated with either of these pathologic conditions or occurring as an isolated process may be found a thickening of the ligamentum flavum (Fig. 122). This structure of yellow elastic tissue passes from the superior and upper margin of one lamina to the midportion of the undersurface of the lamina next above. At the anterolateral edge it fuses with the capsule addition swelling of the elastic fibers and thickening of the surrounding connective tissue may occur. Occasionally there may be extensive bony replacement of the ligamentum flavum. The authors have encountered instances in which as much as three-fourths of this ligament had become ossified.

Inflammation may play a part in the pathologic picture. This is attested by the intimate adhesive attachment of the root

to either the disk or the ligamentum flavum, or to·both. Since these adhesions prevent free movement of the root, they contribute to the basis of pain and may complicate the surgical approach to alleviation of the difficulty.

Clinical Considerations. At the present time these basic processes—herniation of

burning, or stinging in character, appearing low in the back or in the sciatic distribution or both. This pain· is usually increased in severity by any process which would raise the intracranial pressure, such as coughing, sneezing, straining, and the like The patient may have found that his pain will be worse when he is up and around



Free fragment
of disk, with compression of nerve root
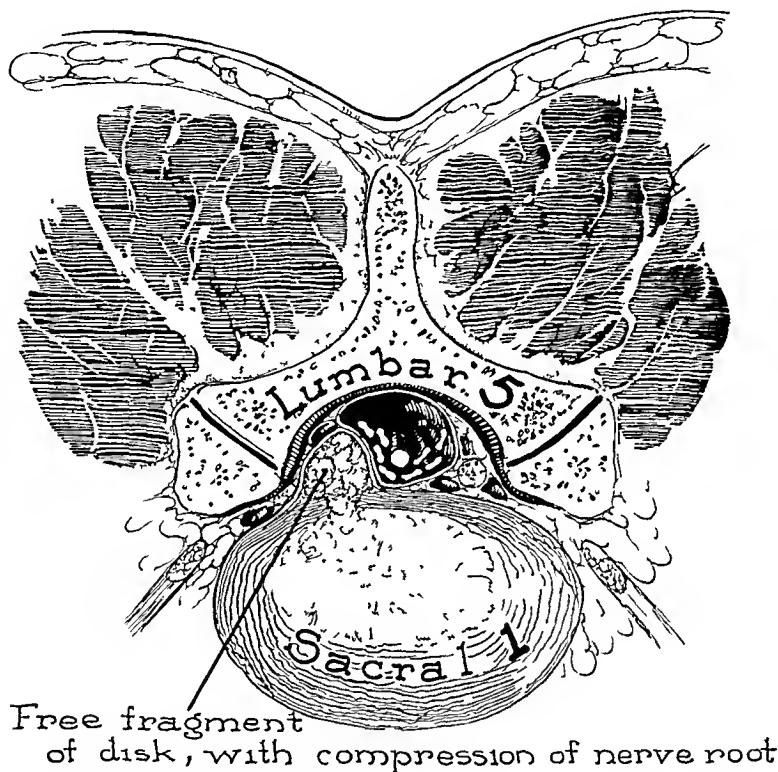
Fig. 219. Same level as Fig. 218, showing extruded material lying between root and dural sac.

the nucleus pulposus, protrusion of the intervertebral disk, and thickening of the ligamentum flavum—cannot be clinically differentiated with any great degree of consistency. The approach to the problem is the same and the physical findings may be identical in the three variants of the syndrome.

The initial presenting complaint of patients with this syndrome is *pain*, aching,

than when he is lying down, or he may dread the approach of night and the prospect of sleepless hours of discomfort. He will have found that boards beneath the mattress of his bed permit more rest, and that "easy" chairs are less comfortable than straight chairs. Degrees of discomfort range from slight transitory pain in the back and along the sciatic distribution unilaterally, or occasionally bilaterally, to se-

vere, completely debilitating pain in which the patient is bent over and unable to obtain relief no matter how he may stand, sit, or lie. The symptoms are variable, with a tendency to exacerbations and remissions.

Most patients are in the third, fourth, or fifth decades of life. Males, being more fre-

affected side is higher. The knee on that side is usually flexed, relaxing any tension on the sciatic 'nerve. Pain and muscle spasm limit bending of the trunk in any direction, but especially forward. Compression of the jugular veins will usually increase the pain, as will coughing, straining, and sneezing. Sharp pressure over the

Free fragment, Sacral 1 with lateral displacement of nerve root
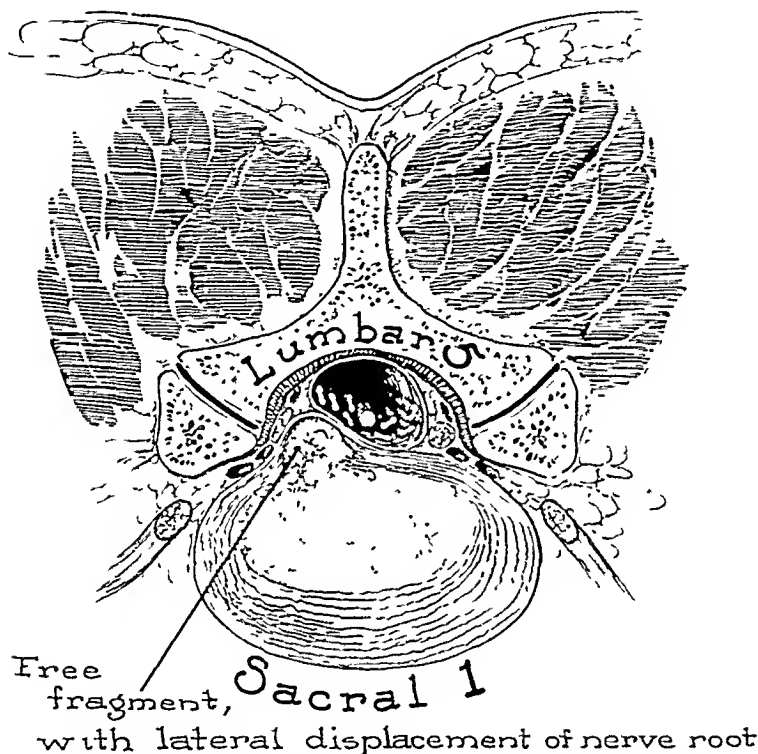
FIG. 220. Same level as Fig. 219, showing marked degree of extrusion pushing root against capsular portion of ligamentum flavum.

quently subject to the conditions fostering the appearance of the syndrome, predominate in most series, approximately 3 to 1.

Examination is usually begun with the patient standing. Observing his *stance*, a distinct list to the side opposite the irritated root in the lumbosacral region is noted (Fig. 223). There is flattening of the normal lumbar lordotic curve. The weight is borne on the sound leg, with the pelvis tilted so that the iliac crest on the

paraspinous tissues at the suspected level will often produce a characteristic pain radiating into the segmental distribution. A similar result follows pressure at the sciatic notch. The tone of the gluteus muscle on the affected side is usually diminished.

Next the patient is asked to kneel on the seat of a chair, facing its back. In this optimum position the Achilles reflex may be tested. It is usually diminished or absent on the affected side.

The remaining examination is carried out with the patient reclining. Weakness of motor power is commonly demonstrable, especially in the dorsiflexor muscles of the toes and of the foot. Diminution of the patellar or hamstring reflex suggests a lesion at the third or fourth disk, whereas

the lower two-thirds of the lateral aspect of the calf.

Straight leg raising on the affected side is usually limited to 30° or less, the limiting factors being pain along the sciatic course and muscle spasm. Lasègue's sign is commonly positive. Forced flexion of the



Posterior bulging of the disk
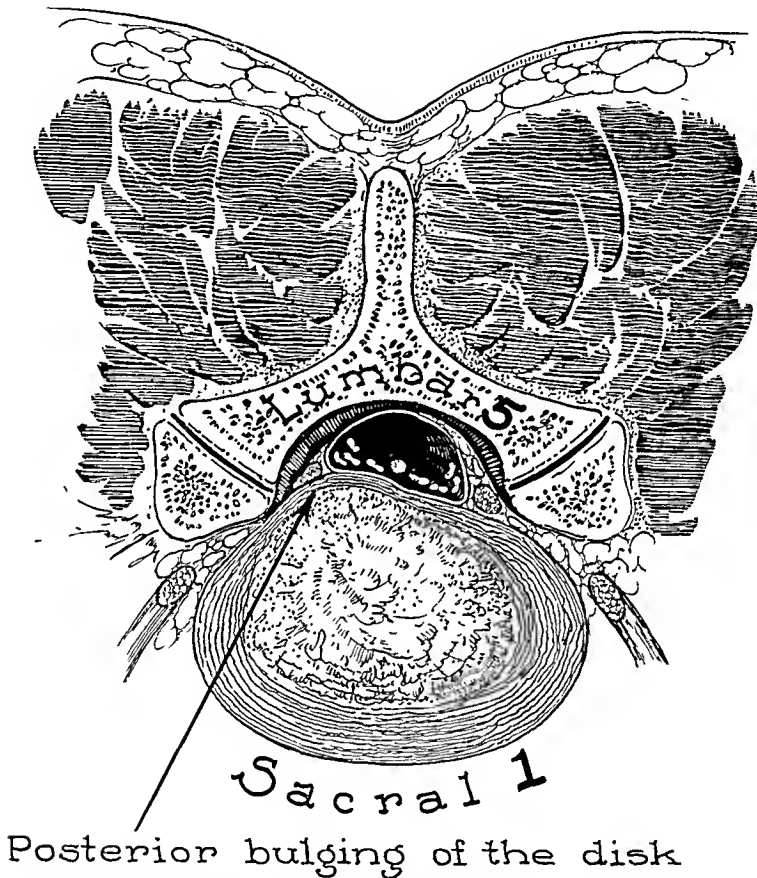
Fig. 221. Same level as Fig. 220, showing a bulging of disk. Capsule is intact. This situation would yield little material at operation.

alteration of the Achilles reflex is more often associated with irritation at the level of the fourth or fifth disk. If the first sacral root is affected, hypesthesia is found over the region of the lateral malleolus and dorsum of the great toe and first metatarsal. Involvement of the fourth or fifth lumbar root is suggested by hypesthesia of

opposite side may cause some discomfort on the affected side.

Plain x-ray films are important in ruling out calcified lesions, osteolytic growths, osteo-arthritic lesions, or other skeletal abnormalities. Their value in making a positive diagnosis of the disk syndrome, however, is slight.

are closely adjacent to the sacro-iliac joint, and disease in that joint, therefore, may involve nearby nerves. It is possible to have hypalgesia over the distribution of these nerves, and even alterations in deep reflexes have been described as a result of a process confined to the region of this joint. Under these circumstances other essential clinical criteria for protruded intervertebral disk are usually lacking.

SPINAL NEW GROWTHS. Spinal new growths either within or without the subarachnoid space must be differentiated. Inasmuch as protruded or herniated intervertebral disk is a tumor, neoplasms within the lumbar sac and those around the dural-arachnoidal sleeves of the nerve roots have been misdiagnosed as protruded intervertebral disks. These may be gliomas, meningeal tumors, or metastatic growths. Often they are not identified until operation is performed and histologic study is carried out, so closely may they mimic the classic picture of a protruded intervertebral disk.

OSTEO-ARTHRITIS. It is possible for osteo-arthritis to simulate protruded intervertebral disk; at times it may comprise a part of the general picture when a disk is present.

SPONDYLOLISTHESIS; EARLY POLYNEURITIS; MEDICATION INJECTED INTO GLUTEAL REGION; SPINA BIFIDA. These conditions may cause the novice concern, but any considerable experience will prevent confusion of these diseases with the intervertebral disk syndrome. Rectal examinations should not be omitted.

Operative Procedure. Usually operation for a protruded intervertebral disk is performed under general anesthesia. In the large, heavily muscled patient, however, better relaxation can be obtained by the use of spinal anesthesia, and, to date, no untoward results have been observed. The usual length of this type of anesthesia, up-wards of an hour, is adequate for the procedure. If the anesthesia does wear off, a small amount of procaine can easily be injected into the spinal subarachnoid space by the surgeon himself, on the advice of the anesthetist.

The patient is placed in the prone position with the lumbar curve flattened out as much as possible by breaking the table rather than by using the kidney lift. The field is prepared in the fashion already described.

Having cut through the skin and subcutaneous tissue it is possible to incise the superficial fat with the electrosurgical unit, which is also used to separate the deep facial attachments to the spinous processes of the vertebra. It is necessary to separate these only on the affected side unless there is considerable evidence to suggest a bilateral lesion.

Muscular and tendinous attachments to the spinous processes and laminae and interspinous tissues are then separated by periosteal elevators, exposing the lateral surface of the spines and laminae out to the articular facets (Fig. 225 A). The loose tissue overlying the ligamentum flavum is thoroughly removed. A sagittal incision is made at the midline through the ligamentum flavum with a small-bladed scalpel on a long handle. In the case of the interspace between the fifth lumbar and the first sacral vertebrae the ligamentum flavum .may frequently be cut with the scalpel from the under surface of the lamina of the fifth lumbar and the upper surface of the lamina of the first sacral vertebrae without the removal of any bone. It is wise to follow the removal well out into the angle between the two laminae and to the anteromesial surface of the joint capsule to permit adequate exposure of the lateral reaches of the spinal canal (Fig. 225 B). In case of exploration between the fourth and fifth lumbar vertebrae it is advisable to remove the lower part of the

lamina of the fourth lumbar vertebra and the upper part of the lamina of the fifth lumbar to obtain a satisfactory demonstra-



FIG. 223. List to right accompanying irritated roots in lumbosacral region on patient's left.

tion of the lateral angle of the canal in this region. The ligamentum flavum having been removed and having been examined for thickness and for evidence of the replacement by connective tissue in its more anterior aspects, the epidural fat and dura may be retracted mesially with a long, slim, flexible retractor ("Horsley spatula"), allowing identification of the nerve root as it

passes to leave the canal one segment below the point of exploration.

All maneuvers following this stage in the operation must be executed with great care to avoid rupturing the large venous channels which are commonly encountered in the epidural space and the tearing of which



FIG. 224. Examination of spinal canal by radiopaque oil, demonstrating needle in place during study, and defect produced by extruded material from intervertebral disk.

may seriously impede the remainder of the operative procedure. It is dangerous to cauterize these vessels, as an overflow of the electric current into the spinal subarachnoid space may cause postoperative paresthesias or interruptions of nerve roots. Clips may be used. Generally a small amount of carefully placed packing of cotton or of gelatin foam soaked in thrombin solution will exert enough pressure on the thin-walled vessels to prevent their bleeding during the operative procedure.

If the herniated part of the disk lies lat-

erally (Fig 226 B), the root may be bound tightly over its surface, sometimes being held by adhesions, so that careful dissection to free the root from the disk may be necessary. Under such circumstances great care must be taken to avoid tearing the dura and arachnoid or injuring the root itself. Both dural sac and root must be
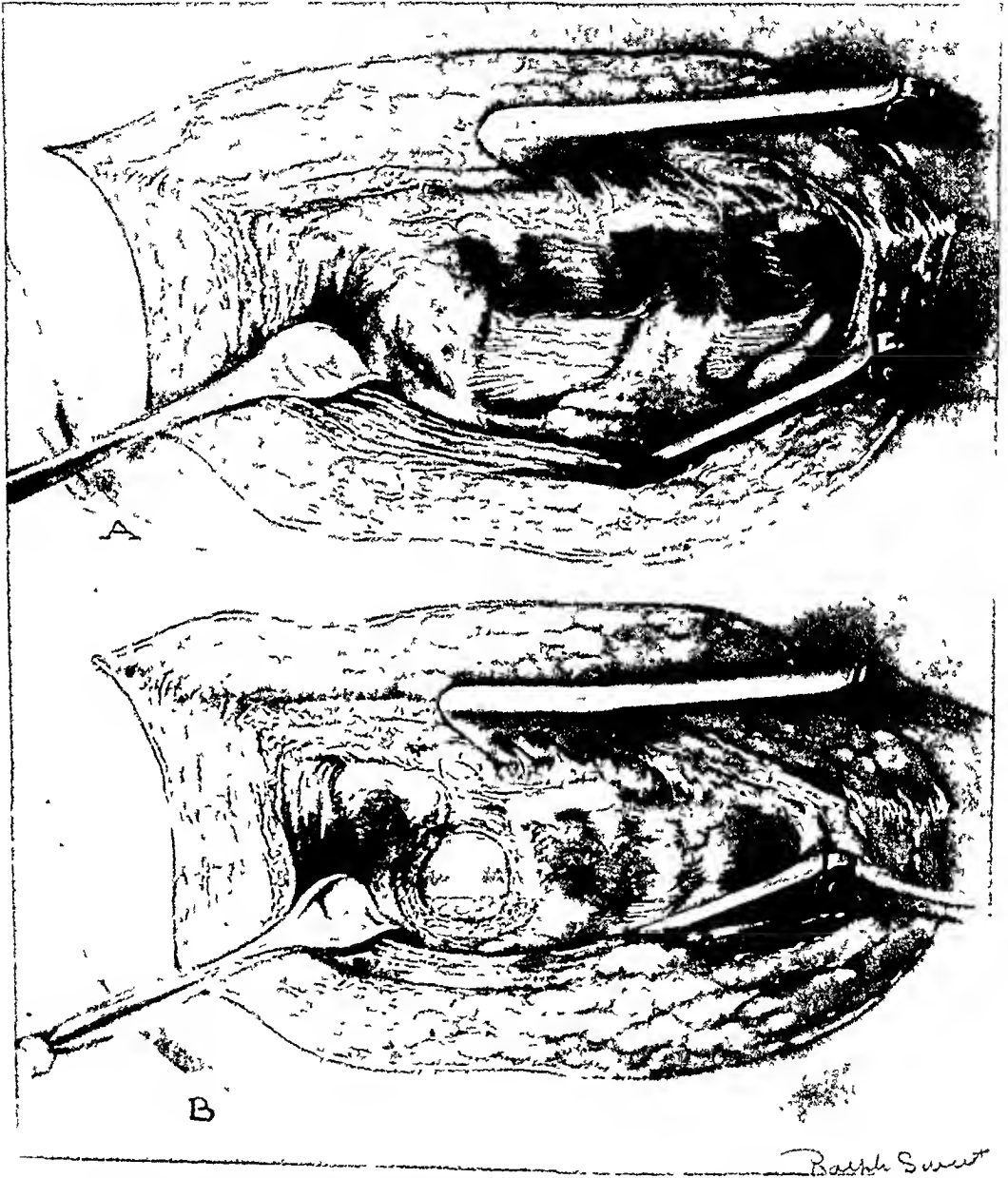


FIG. 225. (a) Unilateral exposure from fourth lumbar vertebra to upper sacrum with ligamenta flava undisturbed. (b) Dura and epidural fat between laminae of fifth lumbar and first sacral vertebrae, seen after removal of ligamentum flavum and small bits of laminar bone.

pressed toward the midline in order to expose sufficient bulk of the herniated mass Should the herniated material lie more mesial it is usually expedient to approach by retracting the dural sac toward the mid-

Occasionally spontaneous opening will be found to have occurred. Once the capsule is opened, if there has been a true herniation of the nucleus pulposus, the extruded material may be lifted out as one or more
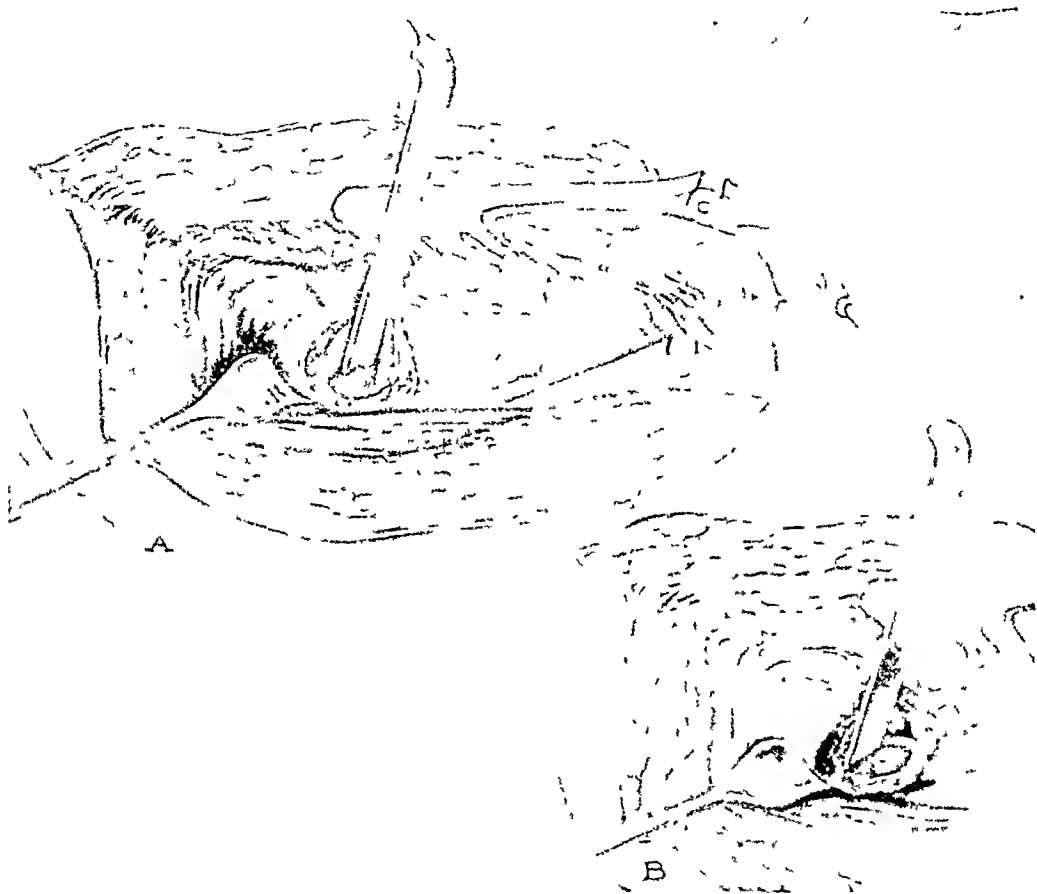


FIG. 226. (a) Extruded disk material at lumbosacral level appearing between dural sac and first sacral root. (b) Same as (a) but with extruded material lateral to both dural sac and first sacral root.

line and the roots laterally. this being particularly true if the roots come off rather high in the canal as they sometimes do (Fig 226 A).

When a herniation of the disk has been identified and exposed, the thin wall of the capsule may be ruptured by the blunt end of an instrument such as artery forceps

pieces of white semi-solid cartilage, nucleus pulposus, and fibrous connective tissue (Fig. 227). When collapse and protrusion of the disk are present rather than herniation, the mass is rarely of sufficient size to produce the taut stretching of the root just mentioned, though adhesions may, on occasion, be present When such a situation

is recognized the root should be decompressed dorsally first. Only when this approach has failed to give adequate relaxation of the root is cutting of the capsule with a knife justified. When the capsule is cut less material is obtained than is usual with the herniated disk. That which can be teased away with tissue rongeurs, hemostats, and the like is mucoid, stringy, and limited in volume.

If no protrusion or herniation is obvious, care should be taken to explore the midline portion of the anterior wall of the canal before concluding that there is no lesion of the disk.

In dealing with either the herniated or

Postoperative Treatment. It is the authors' present custom to keep the patients flat in bed for about seven days. At the end of this time the head of the bed is gradually elevated and the patient's activity is increased so that he is up in a chair by the tenth or eleventh day and out of the hospital in approximately two weeks. Light activity is allowed in two or three months and heavy labor after six months, but with the warning that a weakness of the back was a major factor in the precipitation of the condition for which surgical treatment was necessary and that it is also wise to limit future activity, avoiding bending and twisting of the back and the lifting



Fig. 227. Extruded disk material removed from lumbosacral space.

the protruded disk complex, it is well to curette the intervertebral space and remove any remaining portions. This maneuver may also place the two bodies in closer apposition so that eventually they may become firmly united by fibrous or even by bony tissue. It is necessary to warn against overenthusiasm in the clearing of the intervertebral space and to point out that sharp instruments passing through the intervertebral disk anteriorly have been known to enter the aorta or common iliac artery. After the disk and the packing have been removed, the pressure of the spinal subarachnoid space against the vessels is usually sufficient to prevent further bleeding. If hemostasis is still incomplete, bits of muscle or fibrin foam will suffice.

of heavy weights. The patient is advised to reach the floor by flexing the knees and hips rather than by bending the back. One whose livelihood depends on heavy labor is particularly instructed as to the hazards mentioned above. If he feels compelled to continue, however, a wide belt with stays at the back to limit lumbar flexion has seemed to have some value in checking excessive spinal overactivity.

Women in the child-bearing period frequently inquire regarding pregnancy. So far as the authors are aware, no ill effects have been attributed to pregnancy after operation for the intervertebral syndrome.

Prognosis. With the niceties of precise diagnosis now available and with the minimal trauma of the limited approach to the

lumbar intervertebral disk, the prospect of return to the previous occupation is good in from 80 to 85 per cent of patients operated upon for the syndrome in the lumbar region. This figure may be high for industrial centers; incentive to return to preoperative activity will undoubtedly affect it.

Combined Fusion and Disk Removal. The question of supplemental fusion of the spine at the time of removal of the herniated or protruded intervertebral disk or thickened ligamentum flavum is a topic for considerable debate at the present time. The root of the problem lies in that small percentage of patients who have not received complete relief from all of their preoperative symptoms or have had exaggeration of symptoms at later dates, usually after an early return to labor involving lumbar strain. Those who see only this group tend to brand the current treatment as outlined above as a complete failure and to recommend some form of spinal fusion for all patients with the syndrome. At the present time metal screws through the articular facets, bony fusion of articular facets, and complete fusion with iliac or tibial grafts are used.

Before accepting such a radical change in treatment, or any considerable part of it, the poor results must be completely evaluated. Difficulty following simple removal of the disk may manifest itself in several ways. There may be return of pain in the back and sciatica identical in character with the original symptom complex. This can result from further extrusion of diseased disk material which, in spite of the decompression of the root, may irritate it and the intrinsic sensory nerves of the spine. The course after secondary removal is usually good.

In a second group pain in the back without sciatic radiation may continue. Some of these patients have been relieved by ap-pliances such as a plaster-of-paris cast or a metal brace. In our Clinic a few have had fusion performed with satisfactory results. Our orthopedic colleagues have not recommended fusion if patients have not been relieved by immobilization. After thorough study to eliminate all other possible causes of the pain, these patients have been treated by physiotherapy and by regulation of activity to favor the lumbar part of the spine.

A few patients have been seen who have had pain in the back as a major symptom for months or years, with sciatica as an intermittent and relatively minor factor. All of these patients have been seen with orthopedic consultants. Some of them have shown congenital changes in the offending portion of the spine. In many, after removal of the protruded or herniated disk or after exploration for an irritating disk, the attending orthopedist has fused the lateral joints by removing the articular surfaces and inserting a wedge of bone between the facets. After operation these patients have been kept in bed longer and have had support in the form of a cast or brace or both for three or four months. To date all have done well, but for all of them the postoperative follow-up period is relatively short and the number of patients is too few for valuable conclusions.

At present the authors are inclined to agree with Lewin and others that fusion, if necessary, should be done for its own indications after there has been time for a survey of the effects of removal of the disk alone. Undoubtedly there are occasions when both procedures are indicated and should be done at the same operation. The grouping of such situations will most certainly tend to be more absolute in delineation as experience increases, but at present the necessity for weighing each clinical problem on its own merits seems self-evident.

## CERVICAL INTERVERTEBRAL DISK SYNDROME

The intervertebral disk in the cervical region is anatomically analogous to that in the lumbar region, and is subject to the same progressive changes already noted as occurring in that area. The cervical disk differs in that it is narrower and is more delicately constructed, it is involved in somewhat greater range of mobility; it is called upon to support considerably less weight, particularly in the excessively adipose. Probably it is subject to less trauma. The frequency of clinically recognized herniation of the cervical intervertebral disk is but 2 or 3 per cent of that in the lumbar region.* The sixth cervical disk is more mobile, is more subject to trauma, and is by far the most common location for the offending condition.

The cervical disk syndrome may manifest itself in one of two ways—viz., by pressure on the spinal cord or by pressure on the cervical roots.

Pressure on Cervical Spinal Cord. Until recently this was the more commonly observed and reported of the two types. The first symptom usually is chronic or recurring stiffness in the neck with some associated involvement of the shoulders and arms. Sometimes shocks or stabs of pain result from sudden movement of the head. Generally speaking the patient will not have been incapacited at this early stage.

Acute debilitating symptoms often develop rather rapidly and are those of an extramedullary, extradural tumor at the level and position of the mass (see under Tumors). Tenderness may be present over the spinous process or the lateral masses at the given level. Movement of the head

* This figure is particularly impressive in view of the statement by Saunders and Inman (personal communication) that, in a very high percentage of cadavers studied by the Division of Anatomy at the University of California Medical School, some posterior herniation of nuclear material in the cervical region was demonstrated.

and neck will often increase the symptoms, particularly any associated root pain.

The spinal fluid may show slight increase in protein. The subarachnoid space may be partly or wholly blocked. Radiopaque material within the canal will usually show the level of the lesion even when the block is incomplete.

Surgical Treatment. The surgical treatment is that already described under extradural tumors of the cervical region.

Pressure on Cervical Roots. The syndrome resulting from the pressure of a fragment of herniated disk on cervical roots, without involvement of the cervical cord, is gaining increasing recognition. Semmes and Murphey have published a review of this type which has aided in the clarification of the syndrome.

Most of these lateral herniations occur between the sixth and seventh cervical vertebrae, with involvement of the seventh cervical root. The history is that of stiffness of the neck for months or years. Pain between the shoulder blades, over the upper chest, and in the suboccipital region may also occur; intermittency of symptoms is often outstanding. Acute debilitating pain shooting into the index finger on the affected side and involving the other areas mentioned may appear quite suddenly. Semmes' and Murphey's patients reported precordial pain like that of coronary disease at first, which later settled into the rhomboid region and the arm. The acute pain is generally accentuated by any sudden movement of the neck, especially extension.

On examination, usually it will be noted that the patient holds the affected shoulder elevated and the head tilted forward or toward the same side. Some tenderness will be found over the lateral masses at the affected level. Numbness and weakness of movement of the affected forefinger will be in evidence. Manual traction on the head will alleviate the painful symptoms

whereas accentuation will result from pressure on the top of the head.

Roentgenograms of the cervical spine will show straightening of the region with diminution of intervertebral distance at the affected level. Cerebrospinal-fluid protein may be slightly increased. Spinal subarachnoid block cannot exist in this type of the syndrome, but it is our experience that radiopaque oil can show a defect even when the spinal cord is not involved.

Surgical Treatment. One of two surgical approaches to this type of herniated disk may be selected. In the first, under general anesthesia, a complete laminectomy one segment above and below the affected level is carried out. The exposure on the involved side will, perforce, be wide so that there will be good visualization of the root. This root will be pushed dorsally by the mass projecting from the anterolateral wall of the canal and will have been caught between the mass and the yellow elastic tissue and bone forming the posterior wall of the canal. The necessity for better exposure above or below the root will be self-evident, and the piecemeal removal of the tissue can be accomplished without injuring the nerve.

The second approach, recommended by Semmes and Murphey, is carried out under local anesthesia. The laminae are exposed and the affected root is precisely identified by reproduction of symptoms when pressure is exerted on the ligamentum flavum overlying it. The ligamentum flavum with a small portion of the laminae on either side is then removed, exposing the root which will have been displaced dorsally by the disk. Removal of part of the articular facet and the capsular portion of the ligamentum flavum will insure adequate exposure. The root is then retracted upward or caudally and the bits of disk are removed.

Because of the marked difference in the size of the original disk and the greater vulnerability of the intraspinal content, the quantity of extruded material is generally much less in the cervical region than at the lumbar levels.

Prognosis. The prognosis in those patients with the first type of cervical disk syndrome is governed almost entirely by the extent of the damage to the cord associated with the lesion. In the cervical region a second accumulation of extruded disk material at the same level is unheard of. Herniation at another level, however, remains a possibility.

Our experience agrees with that of others who have reported upon this syndrome, that the cervical root type offers a reasonably good prognosis. Residual numbness, tingling, and weakness in the index finger may persist for months or even indefinitely. Some ache in the pectoral and interscapular region may be mentioned for a time. It must be remembered that neuritis has been present and that the removal of the instigating factor merely sets the stage for progressive recovery of the bruised nervous structure.

The factors which have made such an issue of spinal fusion in the lumbar region do not exist with respect to the cervical level. Fusion is probably never indicated at the time of initial surgery. The possibility of luxation after an extension cervical laminectomy must not be forgotten, however, as a potential cause of future distress.

## TUMORS OF SPINAL CORD

Recognition of tumors in the spinal canal does not involve the same difficulties or as detailed neurologic knowledge as do intracranial tumors, but in general the same three diagnostic criteria hold. Whether in the head or in the spine, a tumor must be suspected when the neurologic findings can be explained on the basis of a *single* lesion. If the neurologic signs indicate a spread, it is evident that the single lesion is also *progressive*. When both of these conditions

are met, the diagnosis of a growth must be favored until it is disproved If, in addition, this single and progressive lesion is space-consuming, so that it is causing pressure, the diagnosis may be considered proved. In the case of intracranial tumors, this last characteristic is evidenced by the various signs of intracranial pressure: choked disks, alterations in the bones of the skull, or a measurable elevation of pressure as as a small tumor may be present in the canal without giving signs. The fluid-filled space about it permits a growth to considerable size before contact with and pressure upon the cord is sufficient to produce signs and symptoms. It is not until there is counter pressure against the opposite side of the canal that the neurologic signs become marked. By that time the pressure on the entire cord may be so equalized that
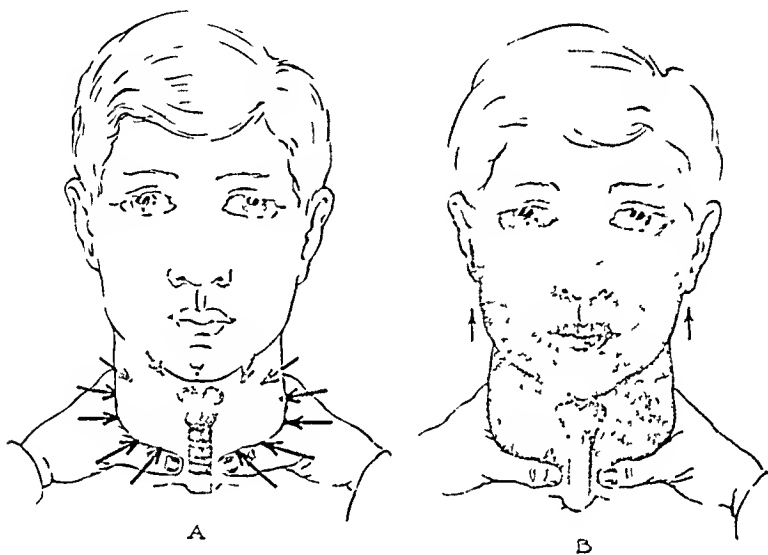


FIG. 228. Neck-compression test

shown by spinal puncture In the spinal canal it is shown by the Queckenstedt test indicating blockage of the canal, by alterations in the roentgenologic appearance, enlargement of the canal, alterations in pedicles, laminae, intervertebral foramina, etc.

A neoplasm, then, is a single, progressing "chorophagic" or "choroplethic" lesion. Other signs by which we recognize this last characteristic arise from pressure upon or distortion of certain structures. Involvement of a nerve root with traction upon it may cause early pain. The spinal cord by no means fills the canal, consequently compression of the cord may not appear early pathways in both sides may show involvement. When root pains have been present their location indicates the site of the growth. Exertion, coughing, sneezing, and straining may precipitate them.

A useful diagnostic test to differentiate from other types of pain the radicular pains caused by a gross surgical lesion is as follows: With the patient in a comfortable position and free from pain, the veins of the neck are compressed until the patient's face becomes markedly engorged (Fig 228). If the characteristic radicular pain is produced it is evident that the increased intracranial pressure transmitted through the spinal fluid has caused a shift in the rela-

tions of the lesion and altered the pressure upon the root. This permits differentiation between a gross lesion acting mechanically upon a root and pains from other causes produced by coughing, straining, etc., which may be caused by muscular contraction producing movement of other sensitive skeletal structures. When this sign is present, as it is in a high proportion of surgical lesions, it readily indicates the mechanical nature of the process.

ery may be anticipated. In this favorable category are the arachnoid fibroblastomas (endotheliomas, meningiomas, or meningeal fibroblastomas) and the perineurial fibroblastomas. These vary in size but many are rounded tumors 2 or 3 cm. long. The perineurial fibroblastomas are attached to nerve roots (Fig. 229). The meningeal tumors (Figs. 230, 231) may occupy any position with reference to the cord—ventral, dorsal, or lateral—influenced some-
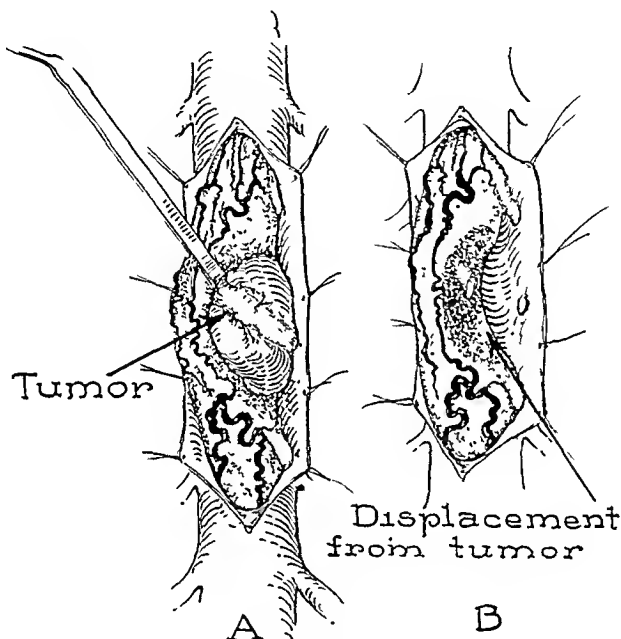


FIG. 229. Perineural fibroblastoma.

Of the primary neoplasms affecting the cord and nerve roots, about half are a joy to the surgeon, for they are encapsulated, single, benign, and accessible. In position they are intradural but extramedullary. In most instances their attachments can be removed with enough margin to insure safety from recurrence. In these the result obtained depends upon the length of time and the severity of the compression of the cord before it is relieved. If the diagnosis is made and treatment given before paralysis is complete, a satisfactory degree of recov-

what by the attachment of the dentate ligament. Some of the tumors extend along nerve roots to become extradural. Resection of all involved structures is essential to prevent recurrence, and removal of a margin of dura to a distance of approximately 0.5 cm. from the attachment of the tumor is necessary.

The width of the bony exposure at the level of the tumor must be sufficient to allow adequate working space for the safe management of the cord. After opening the arachnoid, slight degrees of manipulation

or rotation of the cord may be obtained by traction on a severed dentate ligament A meningeal tumor, if springing from a dorsal or dorsolateral attachment, is ordinarily not difficult to remove. Its sessile base may be surrounded by the dural inci-

Added compression, contusion of the cord or damage to its blood vessels, with immediate or later thrombosis, is an ever-present danger. Under such conditions, removal of the tumor and an adequate area of dura may be difficult Resection of a root may
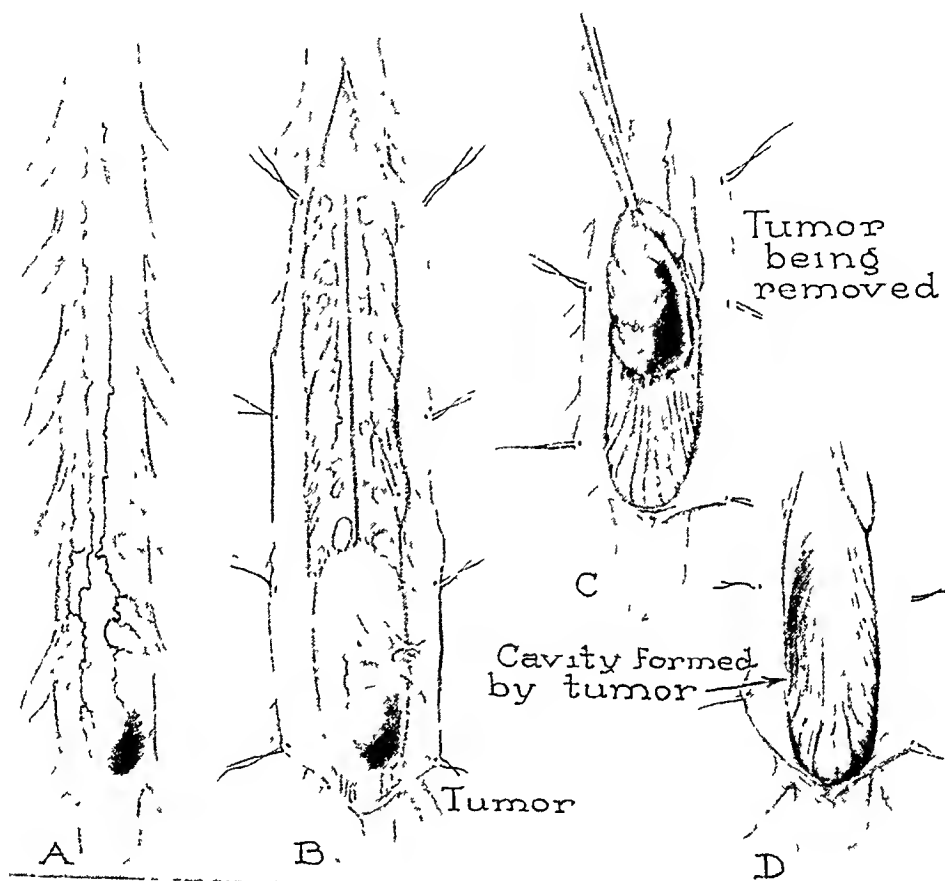


Fig 230. Meningeal fibroblastoma (meningioma).

sion and with gentle traction and dissection with moist cotton it may be separated from the hollowed-out bed indenting the cord. These tumors, though attached to the dura, may be surrounded by infolded arachnoid which must be torn open.

When the origin of the growth is ventral or anterior to the dentate ligament, the risk of causing slight additional compression of the cord during removal is great

be required Except in the brachial and lumbosacral plexuses, such removal leaves no obviously impaired function.

The surface appearance of these perineurial growths is very similar to that of the arachnoid fibroblastoma, which also is smooth and encapsulated but swings from a root and may extend along it. When the arachnoid is opened the root and tumor are resected after placing small silver clips on

PLATE II
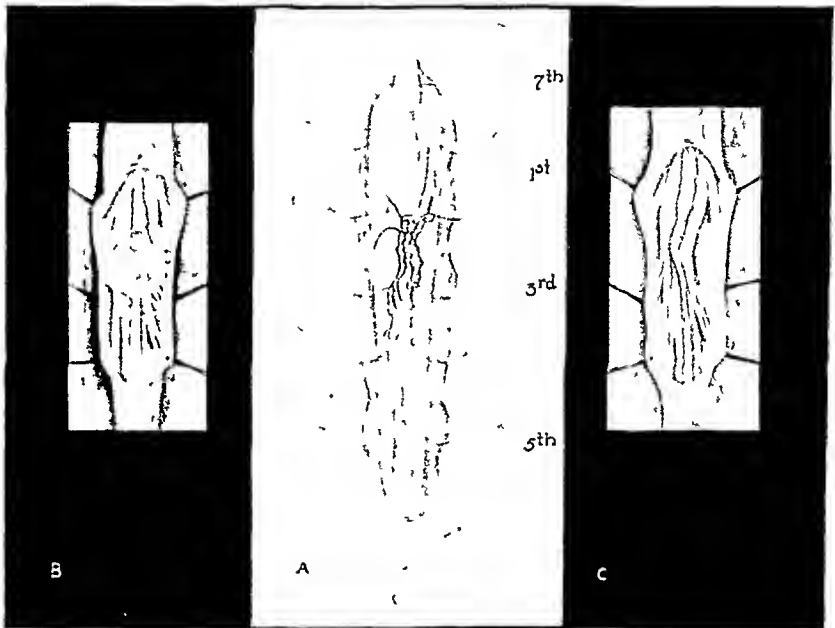


FIG. 231. Meningeal fibroblastoma (meningioma).

each side for control of the associated small vessels. Resection of the dura and the penetrating nerve root is required when extension has occurred. Such tumors may be multiple, as in von Recklinghausen's disease. At one operation the authors have re-materials to be free from irritating effects. Particularly careful hemostasis is required and the muscle and fascia are closed in the utmost detail.

Among the other extramedullary growths, the giant tumors of the cauda equina are
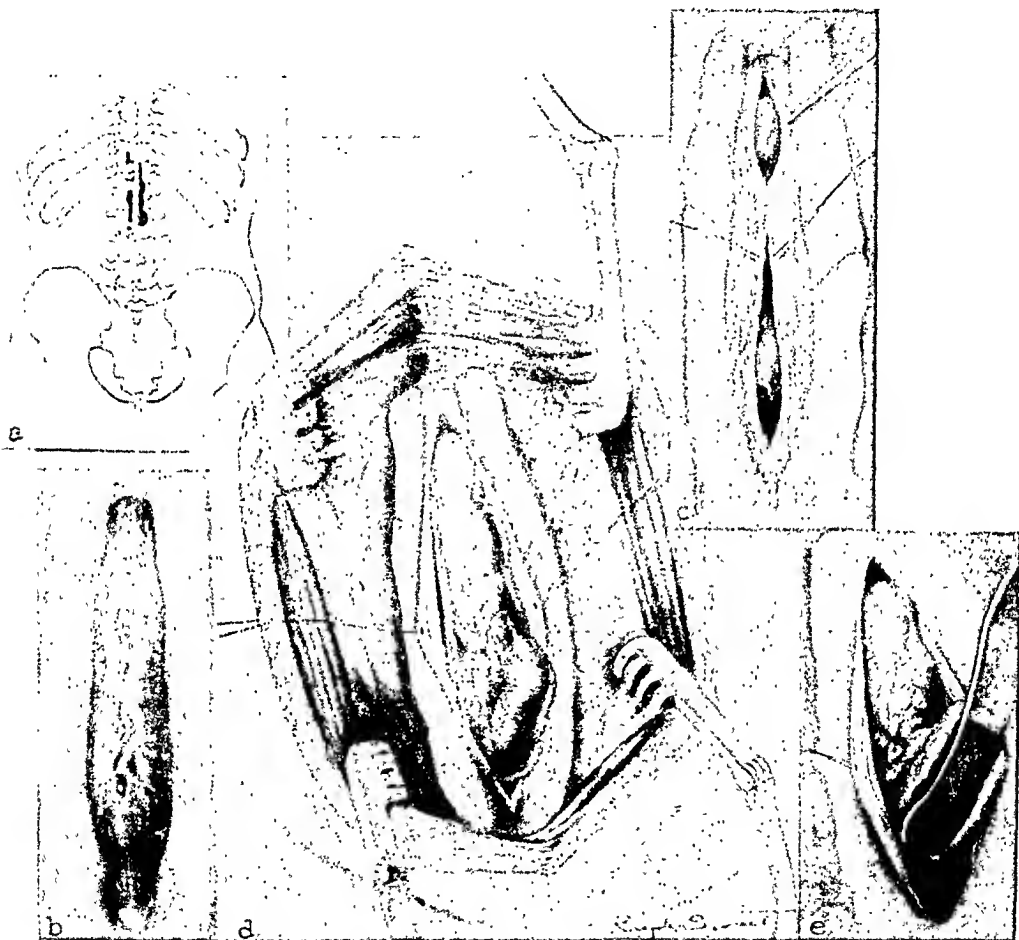


FIG. 232. Giant meningioma in lumbar canal.

moved as many as seven separate tumors, five of them intradural tumors.

It has not been customary to attempt repair of the dura when its resection has been necessary. Recent use of human fibrin film or gelatin foam soaked in thrombin solution for such defects has shown these impressive. Huge growths of several varieties may enlarge the spinal canal and crowd the cauda equina to the wall so that it is almost inconceivable that any impulse could pass through the fibers; yet the patient may present, perhaps, no difficulty other than bilateral sciatica. Such slow-

growing tumors as the giant meningiomas may attain enormous size (Fig. 232). The paucity of symptoms is less surprising when causes less compression. Certain growths of congenital origin, the epidermoids, may be equally large, but the accumulation of
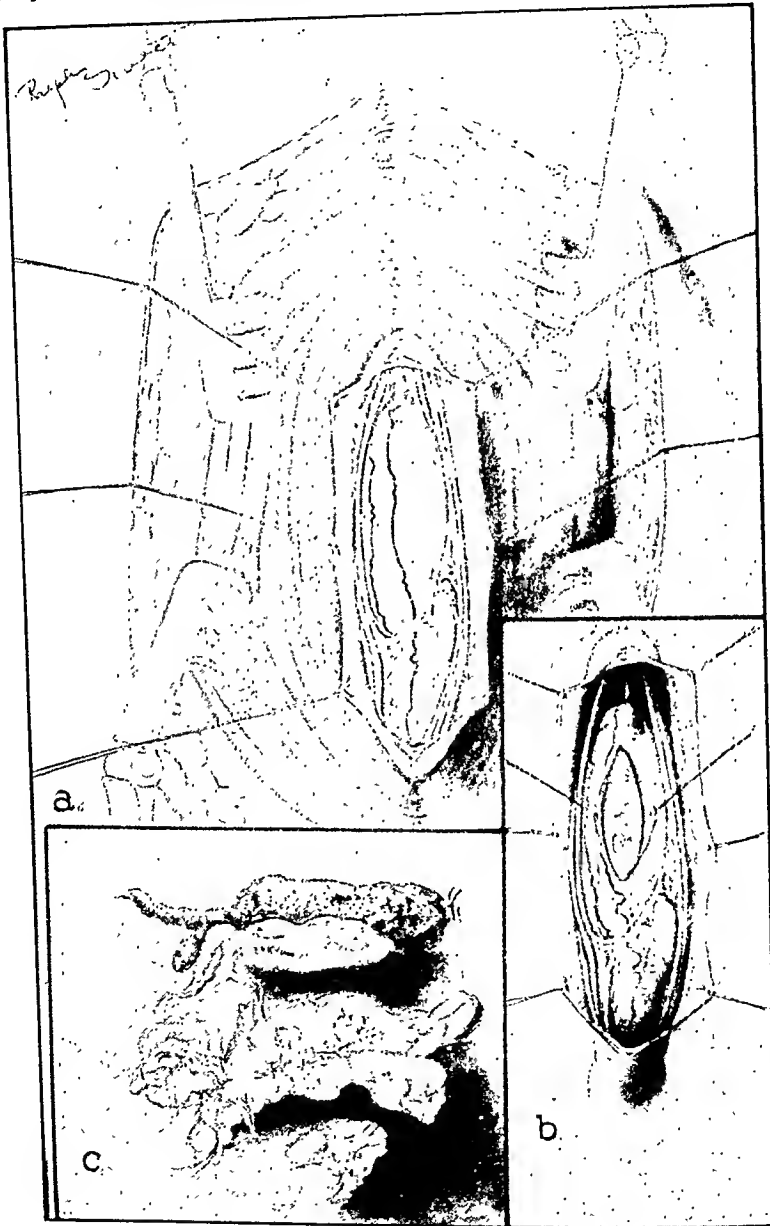


FIG. 233. Epidermoid tumor.

the lumbar canal is filled with a meaty, un-encapsulated, cellular neoplasm such as an ependymoma which, though as extensive, yellow, cheesy, sebaceous-like material, containing hair and cholesterol crystals, forms a sac more or less adapting itself to

the canal and its contents (Figs. 233, 234).

Tumors of the filum terminale also may attain considerable length and bulk (Fig. 235). Certain of the large tumors of the spinal canal so obliterate the spinal-fluid spaces that no fluid is obtainable on puncture. The filaments of the cauda equina normally float freely in fluid and displace readily, but when they are held in a fixed position by a growth spinal puncture may cause extreme pain. Such a painful dry puncture should be suggestive of tumor and any material obtained in the lumen of the needle should be examined microscopically. A pathologic diagnosis is sometimes possible.

The large, smooth, encapsulated tumors often occupy the center of the enlarged or expanded lumbar canal, crowding the filaments of the cauda to each side. With the arachnoid widely opened, complete removal of the tumor may be surprisingly easy. On the other hand, piecemeal removal with a curette may be required for the epidermoids and the cellular meaty tumors which have burst their confines and extended into all the interstices of the roots. While unsatisfactory from a surgical standpoint and manifestly incomplete, the relief of compression, with or without subsequent deep roentgen therapy, may produce highly satisfactory improvement.

The incidence of hourglass tumors of the spine is sufficiently high to indicate that x-ray diagnostic studies are incomplete unless angled projections designed to show the intervertebral foramina are always taken in addition to the anteroposterior and lateral projections for the study of bodies, laminae, pedicles, and spinous processes. These tumors enlarge through the intervertebral foramina. In the neck, palpation may reveal the extravertebral portion of a dumbbell or hourglass tumor. In the thorax, x-ray examination shows them. In the abdomen, they are not often palpable but may be observed by x-ray.

The presence of root pains may give a clue to their presence. These radicular pains may, however, be misleading, as witnessed by the inoffensive appendixes and gallbladders which have been tried, adjudged guilty, and guillotined when the true culprit was a neoplasm. The neck-compression test would usually have prevented such an error. A large proportion of these tumors are of neurogenic origin arising from the cerebrospinal or sympathetic roots and rami. True chondromas, lipomas, and growths originating in the blood vessels also are not infrequent. Hourglass tumors ordinarily present the constricted portion at the intervertebral foramen, though it is not unusual to encounter an extramedullary but intradural tumor which has extended along a nerve root to the extradural space and, after enlarging, eventually has passed through the foramen.

By the time hourglass tumors are recognized as such, the treatment of the neurologic features are of paramount importance either because of progressing paralysis or pain. The laminectomy then is performed prior to the removal of the extravertebral portion. Resection of the intraspinal involvement and cauterization of the cut surface at the first stage, being more urgent, can be followed by the extraspinal procedure at a later time. For the cervical portion, deep dissections of the neck in the posterior triangle are required. In the thorax, careful marking of the location by the roentgenologist permits an accurately directed operation and limited removal of rib as for mediastinal tumors. Completion of the intraspinal operation at previous laminectomy prevents such accidents as tearing of the dura in a thoracic removal of neurogenic tumors. Such misadventures have led to postoperative hydrothorax from the leakage of cerebrospinal fluid. For exposure of the lumbar region the various anatomic approaches used for lumbar sympathectomy are adequate.

Displaced nerves

Epidermoid tumor of
lumbosacral canal
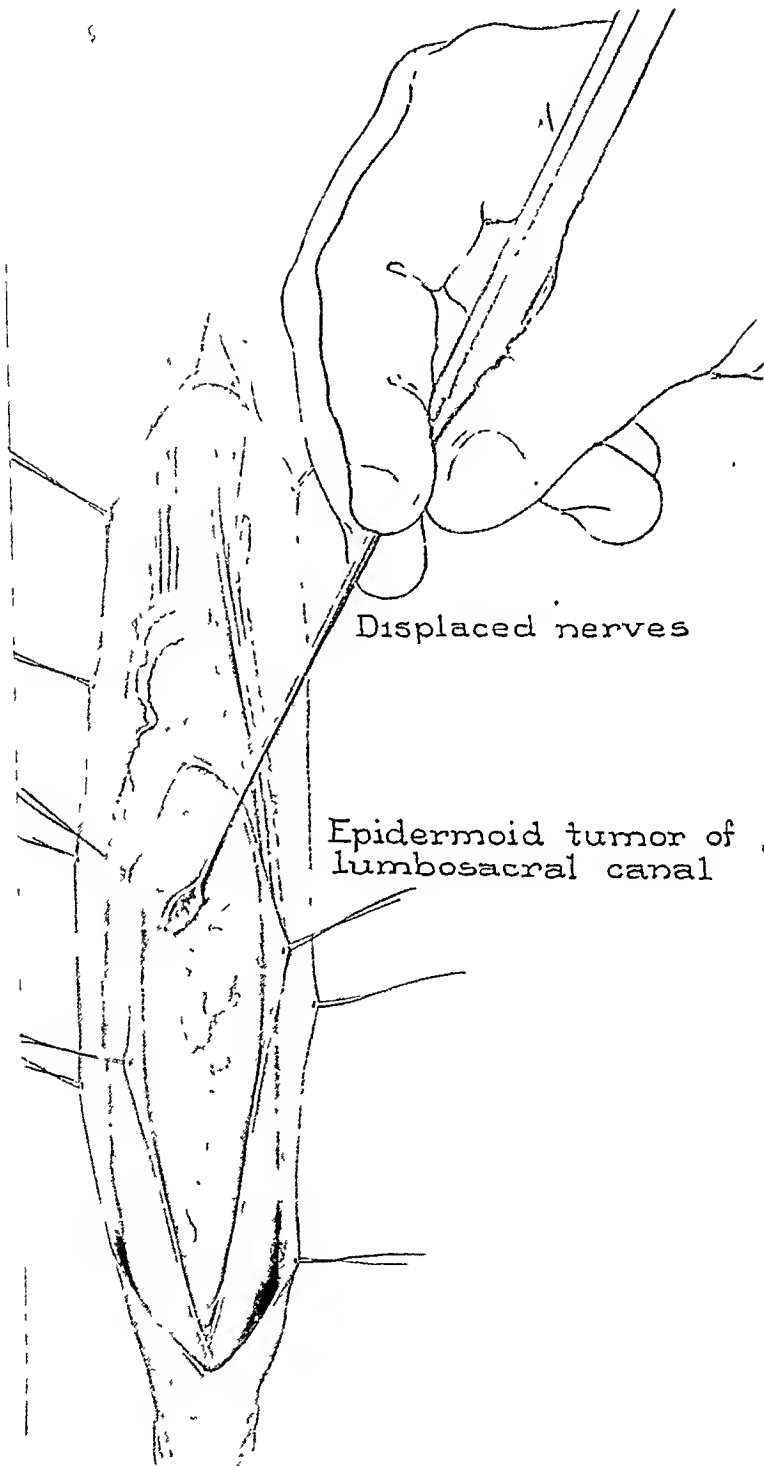
FIG. 234. Epidermoid tumor.
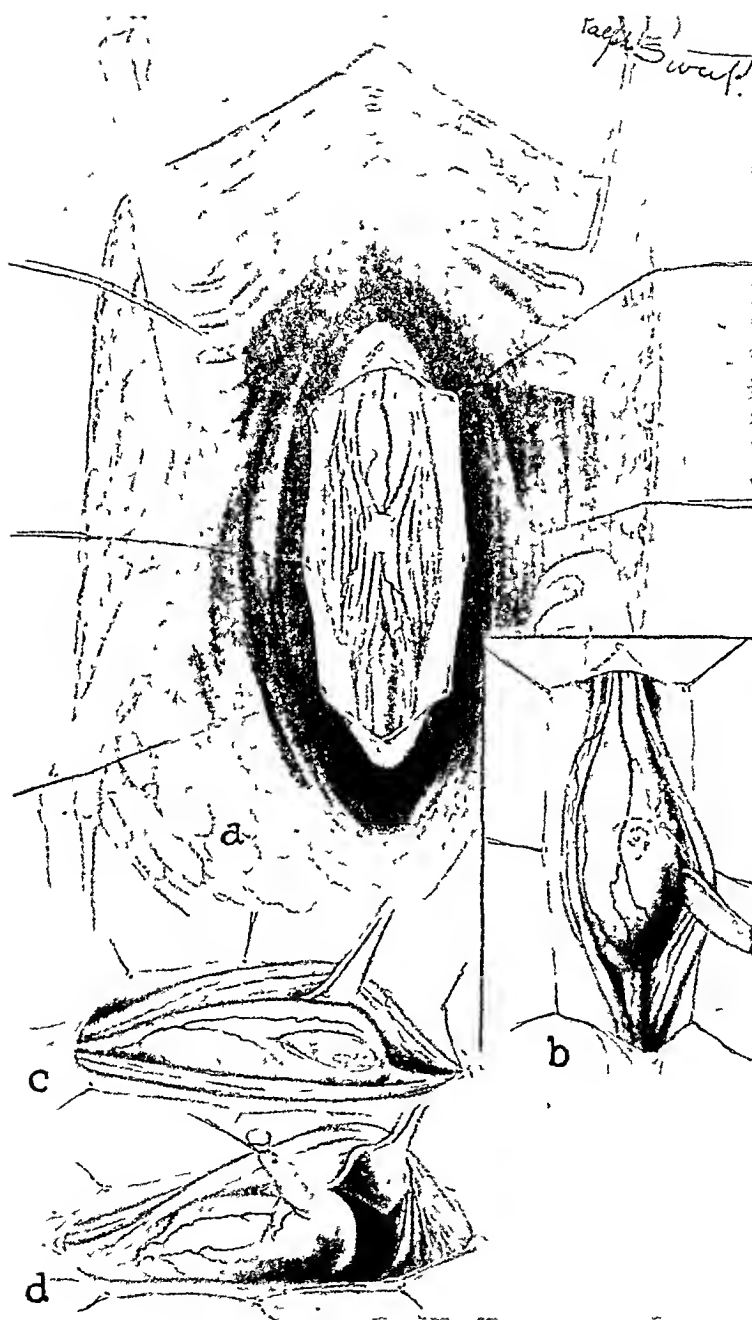
FIG. 235. Tumor of filum terminale.

Apart from the hourglass tumors mentioned as extending through the intervertebral foramina into neck, chest, and abdomen, an occasional one is seen in which the intraspinal portion connects through an interlaminal space with an extraspinal portion lying in the spinal muscles.

It is fortunate that the intramedullary neoplasms are relatively infrequent. Of these the gliomas and ependymomas are any part of the cord or may extend its entire length. The patient's neurologic findings may range from slight changes to complete incapacity. Tumors located in the cervical cord may affect such necessary functions as respiration and the use of the upper extremities and those in the lumbar region, control of the sphincters, and locomotion. Incision into the spinal cord, manipulation, and attempted enucleation of a
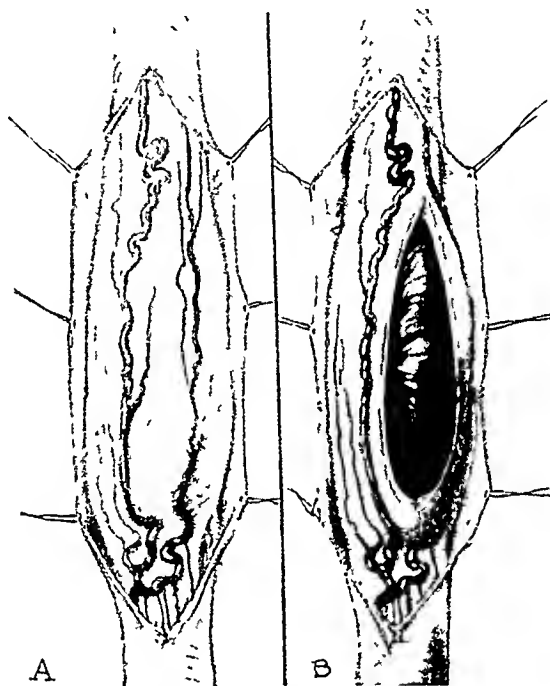


FIG. 236. Incision of dorsal columns for intramedullary tumor.

commonest, though other varieties and granulomatous lesions are occasionally seen. The former are more likely to be in the posterior half of the cord. When confronted with such lesions the surgeon may regret his decision, whatever it is. Several methods of management are open and numerous factors affect the course to be chosen. Some of the growths are fairly well circumscribed. Their vascularity and attachments vary widely. They may involve tumor will cause added damage and possibly serious contusion or hemorrhage. Most of such tumors are invasive. Some respond to decompressive opening of the dura and roentgen therapy.

Longitudinal incision of the dorsal columns in an avascular area and particularly in one where the bulging columns indicate that but few fibers overlie the lesion often permits extrusion of a considerable portion of the growth either at the time or subse-

quent to closure of the wound (Fig. 236). Elsberg advocated two-stage procedures of this type, removing the growth at the second stage if extrusion is complete. Whether this course is pursued or decompression ration may be attempted. Cystic cavities may be evacuated. To prevent refilling in syringomyelitic cavities, Frazier recommended the placement of a few silk threads with the aim of producing a fistulous tract



Tumor in muscle
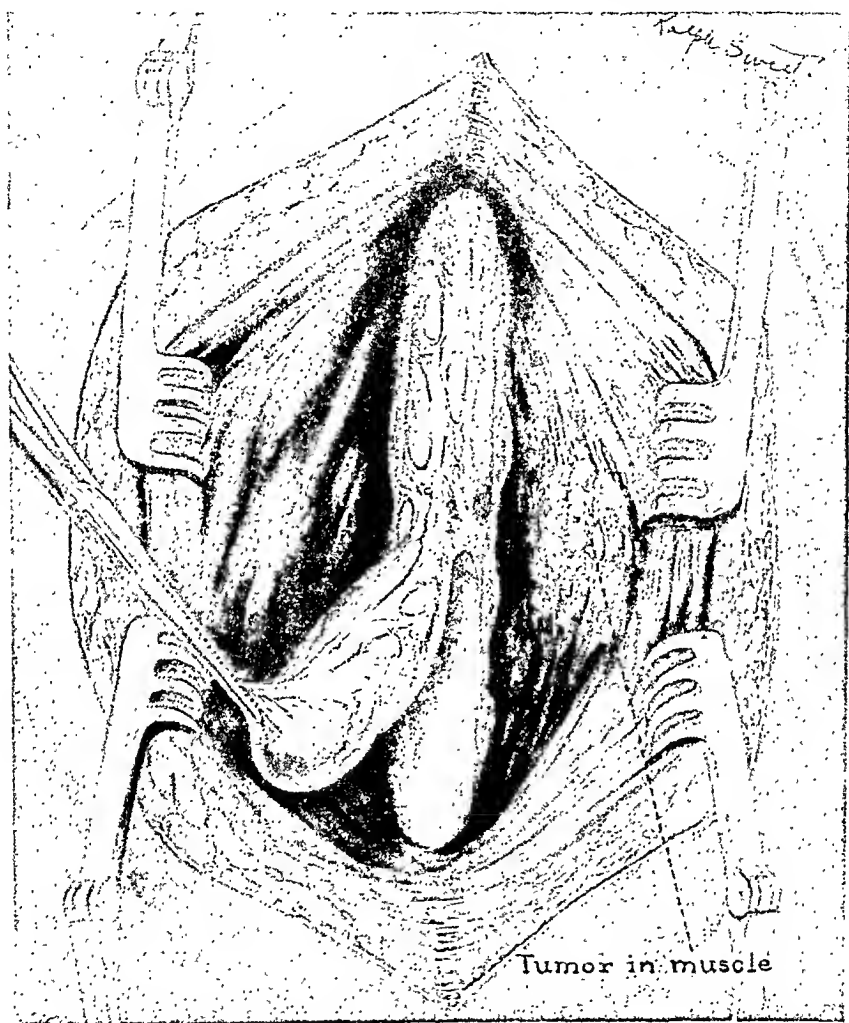
FIG. 237. Extradural fibromyosarcoma.

alone is to be used often is determined by the disability of the patient. If it is slight and increasing but slowly, radical operation may be deferred, pending the effect of decompression and deep x-ray therapy. Prior to incision for intramedullary lesions, aspi-

to the subarachnoid space. Though some reports have been encouraging such tracts are prone to close.

Tumors of blood vessels may be encountered extradurally and intradurally. These are likely to be extremely vascular—for

example, the hemangioblastomas and extra-dural meningiomas (Fig. 237). Clear cysts may occur extradurally, intradurally, or as connected cysts. They are readily opened and obliterated

Secondary or metastatic growths origi-nate from many sources, most commonly from the prostate, breast, or uterus. When the lesion is progressing slowly, laminec-tomy may be indicated to permit decom-pression for relief of oncoming paraplegia or severe pain In many instances we have found laminectomy necessary by reason of the invasion of the spine in Hodgkin's dis-ease The avascular material is readily scooped out Intracranial lesions may give rise to implants in the spinal canal. Such associated lesions suggest certain gliomas, notably medulloblastomas and echinococ-cus infestations which may be disseminated from intracranial sources.

## INFLAMMATORY DISEASE OF SPINAL CORD

### EXTRADURAL ABSCESS

Extradural pyogenic inflammatory proc-esses may occur as a complication of any similar process elsewhere in the body. Or-ganisms may reach the epidural space by way of the blood stream, by direct exten-sion, or as the result of foreign bodies en-tering the space from without. The meta-static group constitutes nearly two-thirds of the entire number and of these a high percentage is secondary to furunculosis. In-fection by direct extension most commonly is secondary to spinal osteomyelitis, medi-astinal and retroperitoneal infection, or pulmonary abscess. Wounds by bullets and other missiles or sharp objects, and com-pounded lesions involving this region ac-count for the remainder.

Though no region may be regarded as immune, the middle and lower thoracic levels are more frequently affected than is any other area. The relationship of these parts of the vertebral column to such com-mon juxtaspinal sources of infection as lung, pleura, mediastinum, and retroperi-toneal space accounts for their frequent in-volvement in abscess by direct extension. The sluggish venous circulation through the indolent epidural fat may be a factor in metastatic infection.

Most of these lesions are acute and those patients who suffer from processes amena-ble to surgery will uniformly have a his-tory of involvement of the nervous system for but short periods of time. In some re-gions, however, especially the lower portion of the thoracic spine, granulation tissue may accumulate before symptoms cause the patient to seek relief.

Acute Epidural Pyogenic Infection. In this condition the earliest presenting com-plaint is usually pain and tenderness at the site of the infection. Often the pain will radiate down the legs or follow the distri-bution of the locally affected roots. The im-mediate onset may have been associated with trauma or straining. Symptoms will be accentuated by cough, strain, sneezing, or the assumption of positions entailing the distortion of the affected region. In acute abscess, progression of weakness to paraly-sis and of hypesthesia to anesthesia takes place within a few days. Grant (1941) noted the early appearance of complete loss of control of the sphincters. The presence of fever, malaise, and leukocytosis may support the diagnosis of abscess, but their absence should not weigh heavily against it.

The source of infection in metastatic epi-dural abscess often will be obscure. Infec-tion of the skin is accepted as the most common site of origin; however, any of the numerous other well-recognized sources of bacteremia cannot be summarily ex-cluded.

On examination, tenderness at the site of the lesion and the signs of transverse myelitis will be outstanding. The sensitive area will usually lie at the upper level of

sensory loss and will generally be associated with a radicular band of hyperesthesia or painful paresthesia. The clinical evidence of transverse myelitis which is a stage in a dynamic process will vary in degree with the relative factors of time, the virulence of the organism, and individual immunologic resistance.

The performance of lumbar puncture in patients suspected of spinal epidural abscess requires a special word of caution. Though the majority of these lesions lie within the thoracic canal, pooling of pus in the lumbar area should be anticipated even in the absence of any particular sign implicating that region. The tragic effects to be expected following the introduction of a needle into the subarachnoid space by way of an infected cavity are obvious. For this reason Grant has recommended that a deliberate attempt be made to touch the lamina with the spinal needle. Then, with stilet withdrawn, one should proceed cautiously through the interlaminar space allowing sufficient time for thick pus under low pressure, should it be present, to appear at the hub of the needle. Aspiration after each 2 mm. of advance will provide added safety.

As with any other space-occupying lesion within the vertebral canal there will be evidence of partial or complete spinal subarachnoid block. Cell count and protein in the cerebrospinal fluid will be high and Pandy's test for globulin will be positive.

In suspected spinal epidural abscess, the use of radiopaque substances is undesirable. Rarely plain x-ray films may show diagnostic or localizing changes.

OPERATIVE PROCEDURE. Surgical relief of acute epidural abscess is one of the true emergency procedures of neurological surgery, since both the factors of pressure and infection with potential retrograde infected thrombosis are present. Paralysis caused by acute infections may reach an irreversible stage within a matter of hours. Equally great is the hazard that infection may enter the cord itself.

The laminectomy must be carried as far laterally as possible without entering the articular space and must extend to normal-appearing dura at the upper and lower reaches of the exposure. The fatty granulation tissue may be removed with suction and, on occasion, curette, taking great care to preserve intact the cord's most effective protecting membrane, the dura. Projections of granulation tissue toward the anterior aspect of the canal may be pursued a few millimeters beyond the bony edge, but to attempt radical extirpation anteriorly will only yield added damage to the cord for minimal beneficial change in the infectious process.

In the acute, virulent processes the best-reported results have followed open drainage with the use of sulfanilamide crystals beneath loosely packed petrolatum gauze. This permits the wound to granulate from the bottom and should reduce the opportunity for the formation of sinuses, burrowing of the infectious process into fascial planes, or the establishment of actual intraspinal abscess by infected retrograde thrombosis. In subacute infections it may seem safe and therefore desirable to close the wound as in chronic abscess. This will reduce the period of morbidity if evaluation of the virulence of the organism and resistance of the tissues has been correct.

Sulfanilamide must still be considered as the most preferable of the sulfonamide group for local use in the vicinity of the central nervous system. Postoperatively the local drug is augmented with adequate amounts of the sulfonamide of choice administered enterally or parenterally. The local and parenteral use of penicillin is still in its early stages as a method of treatment for spinal abscess. It is most promising however for the control of infection by sensitive organisms.

**Chronic Epidural Abscess.** Chronic

epidural abscess, which is only about one-third as frequent as the acute type, may arise from sources of infection similar to those noted for acute processes. The essential difference is that the virulence of the organism is low or the patient's resistance to it is high, or both

Intermittently progressive symptoms and signs of chronic abscess may be present for over a year The authors had the care of a patient who showed evidence of a partial subarachnoid block for several months before surgery was accepted. The general clinical course parallels that of epidural new growth more closely than does acute epidural abscess Local tenderness is not usual; paresthesias and radicular pain are usually intermittent, flaring up with exacerbations of the underlying disease. Evidence of transverse myelitis, being slower in progress, is less likely to reach that degree which so often appears in the patient with an acute process, before proper treatment can be carried out

The same precautionary measures respecting lumbar puncture in acute epidural inflammatory processes must be remembered when the process appears to be chronic The cytology and chemistry of the cerebrospinal fluid are similarly but, as a rule, less markedly abnormal X-ray films show evidence of the infection more frequently than they do in acute disease.

OPERATIVE PROCEDURE The surgical approach is that described in the discussion of acute infection. Once the laminae have been removed to expose the cord above and below the granulations, the nature of the process will usually be evident Small pus pockets may be seen The fibrous wall of granulations has a characteristic appearance. Sometimes this wall can be dissected from the dural surface, at other times the curette seems to be the safer instrument for removal Attention is directed once more to the prime position the dura holds as a protecting membrane for the spinal cord. Anything weakening the barrier is to be avoided. Too-radical manipulation by the surgeon may cause thrombotic extension to the cord. When the mass contains little evidence of concurrent pyogenic activity and the dural adherence is so intimate as to introduce the potential factor of relevant damage to the dura, decompression alone may be considered to be sufficient. The danger here lies in a general spread of the infection to adjacent tissue, or to the cord, should it become reactivated.

At the present time, at the close of the operation, sulfanilamide or penicillin are the drugs of choice for local therapy. Instead of packing the wound open, however, it should be closed with a few sutures, preferably of stainless-steel wire. Tantalum wire has been recommended but the authors have had no experience in its use Rubber drains to the dural surface for from 24 to 48 hours are recommended

POSTOPERATIVE MANAGEMENT. Postoperative management of acute or chronic infection centers chiefly about the general care of the patient with extensive or complete cord disability, which has been discussed above.

PROGNOSIS. The prognosis in patients with the chronic disease is good but those with acute infections generally have done poorly. Grant reported good results in 10 of 14 patients with chronic abscess, two failing to regain cord function and two succumbing to the disease. Of 34 patients with the acute process 14 recovered, nine remained paralyzed, ten died after operation, and one died before operation could be performed. It is generally accepted that the patient's outlook is proportionately increased by earlier recognition and treatment of the underlying cause *Spinal epidural abscess is an emergency*. With the continued work on bacteriostatic and bacteriocidal materials, the upward trend of therapy of these infections seems assured

Epidural Tuberculosis. This requires special consideration because of the recalcitrant nature of the disease. It is almost always secondary to active vertebral or pulmonary infection and so is a lesion of direct extension. The lesion may be principally purulent with creamy pus extending through the greater part of the epidural space, or it may consist largely of granulative reaction with little or no accumulation of pus. When tuberculous spondylopyosis is the site of origin of the epidural infection, paravertebral abscess (cold abscess) seems more prone to occur.

In the past, laminectomy has been frowned upon as a method of treatment for spinal epidural tuberculosis and the "conservative" therapy of immobilization and traction has been favored. Consequently those patients eventually seen by the neurological surgeon have already reached a stage of complete transverse cord disease. A tendency toward revision of this "conservative" therapy is beginning to appear, however, for, as Girdlestone commented, "patients may recover from tuberculosis but not from paraplegia."

The clinical signs and symptoms of compression of the cord by epidural tuberculous infection are those already noted above under acute epidural abscess. Evidence of tuberculosis elsewhere may give a clue as to the causative factor. Radiographically demonstrable osteomyelitis is the rule rather than the exception, yet the signs of compression of the cord may be the first clinical evidence observed.

Caution in lumbar puncture, because of potential epidural accumulations of pus, is essential. In acute compression the number of cells and the amount of protein in the spinal fluid will be high. The protein may be so high as to cause coagulation after puncture, "freezing" radiopaque material in situ in the subarachnoid space. If the protein is not elevated the outlook for re-covery is worse, since the process has by such time become irreversibly chronic.

OPERATIVE PROCEDURE. The operative procedure of choice is that of laminectomy at the site of the compression of the cord. If the lesion is granulomatous the exposure should be carried sufficiently far to identify normal dura above and below the mass. In the purulent type of infection, however, such an exposure probably will not be practicable. Such granulations as will come away easily should be removed, but more important is the successful maintenance of an intact dura. Following laminectomy, liberal use of bactericidal agents as penicillin or sulfanilamide is recommended to minimize the secondary infection to which tuberculous wounds are susceptible. The wound is then closed without drainage, using catgut or stainless-steel wire as the suture material to be buried. The latter may likewise be used in closure of the skin.

The postoperative care of these patients is as important as, if not more important than, the operation itself. Superimposed on the usual problems of care of the paraplegic patient are those associated with the absolute immobilization essential to the successful treatment of phthisical spondylitis. The one will have been wasted effort without the other. This problem is shared by the orthopedic surgeon and has been discussed in that section of this volume.

### INFECTIONS AND INFESTATIONS OF SPINAL SUBARACHNOID AND SPINAL CORD

Bacterial infection of the subarachnoid space is now generally treated by large doses of sulfonamides, enterally or parenterally or by penicillin. Sulfadiazine enters the cerebrospinal fluid well from the blood stream and is the drug of choice for most infectious processes. Penicillin has been advocated for sensitive organisms, and is usually effective parenterally. Early enthusi-

asm concerning the safety and desirability of intrathecal use is waning rapidly. In fact, the introduction of this material into the lumbar sac may produce a coagulum which will of itself block further use by this route or at least cause most to reconsider the justification for its continuation along this course.

The future treatment of abscess of the spinal cord will also revolve around one of the foregoing methods of treatment. The literature contains but few reports of instances in which these abscesses have been recognized clinically and successfully treated by surgical methods. Function in the cord already will have been destroyed completely and drainage cannot restore it though it may prolong life by preventing the spread of infection.

Infestation of the subarachnoid space by *Echinococcus* is still a rare entity in this country but will be seen with greater frequency following the return of the United States armed forces from lands where the disease is endemic. The central nervous system is affected in from 0.5 to 1.4 per cent of all patients with the disease.

In theory, the hydatid ovum is carried into the stomach where the shell is broken and the hexacanth embryo is born; it penetrates the intestinal wall and is borne to the liver or the lung, or both, and cysts situated elsewhere may be assumed to be secondary daughter cysts. Actually, such is not necessarily the case; the authors have seen an instance of the disease within the craniospinal space without demonstrable evidence of lesions elsewhere in the body.

Patients with echinococcosis usually give a history of contact with sheep and dogs together. The life cycle of the worm requires two such animals and these two are the most common. Human infestation results from ingestion of canine excreta, usually during childhood, hence the observation that hydatid cysts are usually about as old as the patient.

Symptoms and signs of involvement of the spinal cord and spinal subarachnoid space are those of tumor of the cord or similar space-occupying lesion. Often the process will have been diagnosed as poliomyelitis at some time during the course. The history of precipitous advance of the disease from time to time may be obtained; this suggests the rupture of a cyst and the establishment of new colonies at other levels.

The spinal fluid may be normal or it may contain increased numbers of cells and an elevated quantity of protein. There may or may not be a spinal subarachnoid block. When no fluid can be obtained from the lumbar sac, the possibility that the canal has been filled by the hydatid cysts must be entertained.

**Operative Procedure.** No change in the usual exposure of the dura is indicated. When this membrane is opened collections of cysts beneath the arachnoid may give the appearance of underlying gas bubbles. The arachnoid may be opalescent and thicker than normal. White or yellow spots a few millimeters in size, but not uniform in dimension, sometimes are seen. When the arachnoid is opened, clumps of cysts up to a centimeter or more in diameter, containing a gelatinous clear fluid, will be observed. They may be adherent to the white or yellow spots mentioned above. A few tiny opaque granules may be seen grossly in some of the cysts and a smear will reveal a head with its scolices, thus making the diagnosis final.

Great care must be exercised in the removal of these cysts since their rupture will result in dissemination of small daughter cysts or live scolices throughout the wound. When an isolated focus of material is found, the outlook for recovery should be fairly good, but when the history and findings confirm preoperative secondary dissemination the probability of complete relief is negligible.

up completely in the roots of the cauda equina. This in itself can be broken up as described above. Extensive section of posterior roots, however, cannot be carried out below the conus without anesthetizing regions where anesthesia may be regarded as more disquieting than the pain. The danger of protracted or permanent loss of control of the vesical sphincter also requires consideration. For these reasons as meticulous a freeing of the roots as is possible is

## RELIEF OF PAIN

In the order of value for the relief of pain may be mentioned (1) the subarachnoid injection of absolute alcohol, (2) rhizotomy, and (3) chordotomy. Dogliotti, in 1931, recommended the first-named method which has now been given an extensive trial, with variable results.

Subarachnoid Injection of Absolute Alcohol. With the patient placed so that
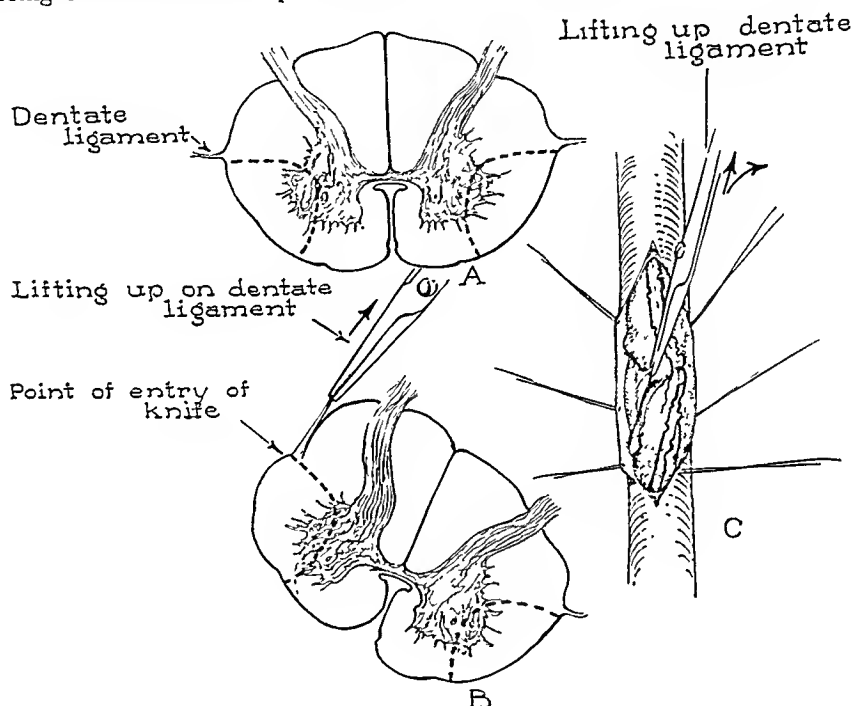


FIG. 238. Incision for chordotomy.

carried out but the nerves are left intact. Since the pain is not so completely relieved as when the roots can be cut, the postoperative course is more troublesome, both to the surgeon and to the patient. Physiotherapeutic methods already mentioned plus passive exercise to force the maintenance of mobility in the joints must be utilized. Again opiates must be avoided. Though convalescence is painfully protracted in these patients, the eventual outcome is generally satisfactory.

the painful side and the presumably involved nerve roots are uppermost, a spinal puncture is performed. The roots of the involved nerves should be at the highest level. One-half or not more than 1 cc. of absolute alcohol is injected. The degree of relief from pain has been erratic and uncertain in duration. Temporary but at times long-continued paralysis of the sphincters has been not infrequent. The method seems to have no wide or enthusiastic support and its efficacy depends upon

the degeneration of roots and pathways. Spinal injections alongside the cord for this purpose carry the obvious hazard of injection into the cord and therefore are ordinarily limited to the lumbar region.

Occasional instances of permanent complete paraplegia with sensory and reflex loss are associated with persistent intense pain at the level of the lesion. For these, alcohol injection directly by puncture into the cord may be considered, or direct injection of the cord through a small laminectomy exposure will give relief.

Rhizotomy of Sensory Roots. This has a place in the treatment of well-localized pain which is not extending to neighboring areas. Its sphere of usefulness is limited by reason of the wide overlap of sensory fields, for the cause of pain is likely to extend and the affected area to enlarge. Rhizotomy does not relieve the postherpetic pain of herpes zoster or the painful phantom limbs which sometimes follow amputations.

Chordotomy. While sections of numerous pathways have been advocated for one reason or another, chordotomy of the anterolateral pathways of the cord, as proposed by Spiller, has stood the test of time. Though Foerster and others have performed chordotomy high in the cervical region for pain in the upper extremity, this procedure involves special risks. Chordotomy is most useful for intractable pain below the region of the nipple and for this purpose the second and third thoracic laminae are removed. The dura and the arachnoid are opened and excessive fluid is sucked out. At its attachment to the dura a dentate ligament is grasped with a mosquito forceps and is cut lateral to the forceps (Fig. 238). By it the cord is gently rotated and an avascular area is selected for section. The point of a fine cataract knife is inserted immediately anterior to the pial origin of the dentate ligament and directed toward the central canal of the cord. The incision is then completed by swinging the point of the knife ventralward so that it emerges from the cord at the origin of the motor root. The deeper the incision the higher will be the loss of the sensations of temperature and pain. The pathways conveying these sensations are composed of fibers having their origin in the opposite side of the body, entering the sensory root of that side and shortly passing across and ventralward in the cord; successive fibers entering at higher levels as they cross come to lie farther from the surface. This lamellated arrangement, then, is such that the lowest sacral segments are represented by the most superficial portion of these tracts. Hence, the deeper the incision, the more fibers will be cut and the higher will be the level of anesthesia. Under local anesthesia, testing of the level permits a deepening of the incision if it is required.

Bilateral section of the tract is required unless the pain to be relieved is unquestionably unilateral in location. When bilateral incisions are made into the cord they should not be at the same level but separated by a centimeter or more to lessen possible interference with the circulation.

Other Procedures. Examination of the detailed anatomic and physiologic concepts which underlie proposals for a variety of intramedullary sections would be out of place in a discussion of operative surgery. In all of these, exposure of the spinal cord follows accepted lines. New procedures which are highly technical and of as yet unsubstantiated value are not included. Root sections for selected cases of spasmodic torticollis present no unusual features in the operative approach. Division of the first, second, and third cervical roots and, at times, the fourth root on the side of greater involvement has yielded perhaps the most satisfactory results.

A word should be said for an operation which has a limited application but which has been a great source of satisfaction in

the authors hands. In certain of the progressive degenerative diseases all voluntary power in the lower extremities and control of the sphincters may be lost. Not uncommonly in these cases there is extreme flexion of hip and knee with great adductor spasm The care of the patient is most difficult, as a sitting position is impossible and the pain from the muscular spasms may be extreme. In these a small exposure of the lumbar enlargement and conus with separation and division of the motor roots to the involved areas has avoided sensory loss and has permitted easier management because of the relaxation and far greater comfort to the patient.

SECTION FIVE

# PERIPHERAL NERVES

# 18

# Surgical Lesions of Peripheral Nerves

CLAUDE C. COLEMAN, M.D.

Surgery of the peripheral nerves is required chiefly for trauma, with tumors of the nerves forming a small but important group of surgical lesions. Peripheral nerve injuries occur with marked frequency in modern warfare, and these injuries have received intensive study in both of the World Wars.

The main peripheral nerves are involved in about 15 per cent of war wounds of the extremities. The literature of peripheral nerve injuries is based largely on the experience with these lesions produced by gunshot or other type of projectiles in war. The high incidence of nerve injuries in modern war has naturally stimulated much research and investigation of these lesions during times of war, but interest in peripheral nerve surgery declines after war even though there may be a steady increase in nerve injuries in civilian occupations due to industrial and transportation accidents.

Injuries of nerves by bullets are relatively rare except during war but division of the nerve by sharp instruments is quite common in civilian life. It is of great importance to apply to the latter type of injury the knowledge gained from the wide experience with peripheral nerve injuries of warfare so that the surgical treatment of these injuries in civilian practice may be put on a more satisfactory basis. The information obtained from the study of peripheral nerve lesions during World War I does not appear to have been utilized to advantage by the profession in the ensuing decades. An effort will be made in this chapter to emphasize the proper treatment of nerve injuries of warfare as well as those of civilian life.

In both World War I and World War II, elaborate provisions were made for the care of peripheral nerve injuries received in military service. The present technic of operation on such lesions was evolved from the experience in the First World War. Many of the problems encountered in the management of nerve injuries at that time still remain, and great optimism as to the solution of some of them is not yet justified. Among the problems requiring further elucidation may be mentioned: (1) Determination of spontaneous recoverability in a neuroma in continuity, (2) methods of direct approximation of nerves when the segments are widely separated, (3) effects on nerve regeneration of delayed suture, (4) effects of important vascular lesions on regeneration of nerves, (5) traction injuries of nerves, (6) use of cuffs of various materials about the suture line, and (7) bridging of gaps by grafts when nerve segments cannot be approximated by any of the established methods.

A precise knowledge of the regional anatomy and of the motor and sensory function of individual peripheral nerves is absolutely essential in the diagnosis and surgi-

cal treatment of peripheral nerve lesions. It is necessary to have not only a thorough understanding of the course of the nerve trunks and their relationships, but also of the origin and distribution of various branches of the nerve in order that these may be readily identified and protected in exposing a lesion. The location and appearance of the nerve which is to be investigated at operation should be clear to the surgeon so that the minimum amount of trauma may be inflicted on surrounding structures and that the nerve itself be protected from further damage during the operative procedure.

If satisfactory progress is to be made in the treatment of nerve injuries of war and peace, something more is required than the intensive study of these injuries during times of war. Greater emphasis must be placed on the teaching of the anatomy of the peripheral nerves to medical students in their clinical years and on the instruction to interns in the diagnosis and treatment of these lesions, if improvement is to be expected in the results of treatment of peripheral nerve lesions in civilian practice. In the author's experience, intern assistants have often expressed great surprise at the size of the median or ulnar nerve at the wrist, having been under the impression that nerves were more or less minute structures. This unfamiliarity with even the appearance of nerves accounts for the failure to identify nerves in lacerated or incised wounds and often results in the deplorable error of suturing nerves to tendons.

The course of peripheral nerves is rarely through muscles but they usually lie in the plane between muscle groups. Notable exceptions to this are the radial and ulnar just below the elbow joint and the anterior tibial. The appearance of a nerve is pale yellowish-white and inspection of the nerve will show an artery running longitudinally in the trunk.

# REGENERATION OF PERIPHERAL NERVES

The fundamental principles of the wallerian theory of nerve regeneration have been widely accepted but there remains some difference of opinion as to many of the minor features of regeneration. According to the wallerian theory, when a peripheral nerve is divided the distal segment of the nerve undergoes degeneration in preparation for the down-growing axis cylinders from the central stump. Degeneration of the peripheral segment is characterized by the migration of Schwann cells from the peripheral stump and these cells attempt to bridge over the defect between the two segments. If this defect cannot be overcome regeneration is obstructed and neuromas form on the ends of the segments. The axis cylinders disappear from the distal stump and Schwann tubes are formed which act as conducting pathways for the axis cylinders which later grow into the peripheral segment. Degeneration for about 2 mm. also takes place in the proximal stump. The axis cylinders from this stump multiply, and under favorable conditions enter the conducting pathways in the degenerated peripheral segment. Scar tissue obstructs the regenerating axis cylinders.

It is now generally believed that the peripheral segment takes no important part in regeneration except to bridge a small gap between the nerve ends and act as a conduit for the axis cylinders to their appropriate terminals. Unfortunately, many of the axis cylinders from the central stump do not find the proper pathways, but it is believed that because of the large number of these regenerating axis cylinders a sufficient number, under favorable circumstances, will reach their appropriate destination. The misdirection of the regenerating axis cylinders and the branching of axons are believed to impair the functional

recovery, and these intrinsic defects of regeneration affect the final results of treatment of peripheral nerve lesions.

The rate of growth of a regenerating nerve has not been definitely determined. It was formerly thought that this rate was about 1 mm. a day, but it is now generally believed that the regenerating fibers grow more rapidly, perhaps as much as 2 mm. daily. Functional recovery is delayed until the regenerating axis cylinders have reached their proper destination, have made connections with both sensory and motor terminals, and have reached a certain degree of maturity. The known rate of growth of fibers of the regenerating nerves makes it possible to estimate with some degree of accuracy the time for recovery of function after suture of divided nerves. Obviously, the period required for regeneration will depend primarily on the length of the peripheral segment of the divided nerve.

The functional results of nerve regeneration in man have not been accurately determined in any large series of cases. Nerve regeneration in experimental laboratories has received a most intensive study, but it is well known that the evidence obtained in experimental laboratories cannot be applied in full as criteria to the regeneration of nerves in human beings.

Criteria of recovery of various peripheral nerves have not been formulated and the terms used to define recovery are neither uniform nor precise. At the present time, the most striking defect of surgery of peripheral nerves is the lack of knowledge as to what it actually accomplishes, that is, what may reasonably be expected from repair of divided nerves, and what residual effects are an inevitable penalty of complete anatomic interruption of the nerve. To acquire this knowledge it will be necessary to establish criteria of recovery for every individual peripheral nerve and to keep patients under observation for at least three years after surgical treatment of the nerve, so the results may be compared with established criteria.

## EFFECTS OF PERIPHERAL NERVE LESIONS

The effect of peripheral nerve injury depends on the type of damage to the nerve. A nerve may be completely divided, thus abolishing all function of the nerve below the level of the lesion. Unless it is known where important branches leave the trunk to supply particular muscles, the interpretation of the motor effects is incomplete and confusing. The most important effects of division of a peripheral nerve are motor paralysis of certain muscle groups and sensory loss with a definite anatomic pattern. Of the two effects, motor loss is regarded as more important. The denervation of muscles is inevitably followed by atrophy. In lesions of certain nerves, such as the ulnar, this atrophy is most conspicuous and is usually permanent to a certain degree.

The sympathetic nerve supply is likewise affected by injury of the main peripheral nerves, causing an absence of sweating in the denervated area. There may be periarticular changes which cause stiffness of the joints, particularly those of the fingers. Periarticular fibrosis is apt to be more marked in partial lesions of the nerve. When the affected limb is allowed to remain in an unfavorable posture the paralyzed muscles become elongated and contractures of the healthy antagonists develop. The stretching of paralyzed muscles delays recovery of function beyond the period of nerve regeneration.

There may be a partial lesion with paralysis of muscle groups supplied by the injured portion of the nerve. Partial lesions of the sciatic nerve are not uncommon. Either the external (peroneal) or internal (tibial) popliteal nerve may be divided, leaving the other intact.

## Nerve Lesions with Associated Vascular Injuries

Nerve lesions are frequently associated with important vascular injuries. Division of the femoral nerve is often accompanied by injury of the femoral artery or vein. Wounds of the ulnar and median nerves are frequently associated with injury to the brachial, ulnar, or radial arteries. Saccular aneurysms and those of the arteriovenous type have been relatively common in World War II. When these aneurysms are in close proximity to important peripheral nerves they may cause an increasing loss of nerve function. Adequate treatment for both the nerve injury and vascular lesion may usually be done at one procedure. There result in such injuries the combined effects of ischemia and denervation. The ischemia may seriously impair the integrity of the paralyzed muscles and prevent that degree of recovery which might have been possible had the nerve alone been injured. Trophic effects of nerve injury such as changes in the skin and hair are common.

## Nerve Injuries Associated with Fracture and Comminution of Bone

Gunshot wounds of extremities often produce comminuted fractures of the long bones. In such wounds there may be extensive damage to the main nerves of the extremity, with considerable loss of soft tissue due primarily to the projectile and further increased by the necessary débridement. This type of wound requires expert surgical treatment.

A rather frequent lesion is that of the musculospiral (radial) nerve in simple or compound fracture of the humerus. The paralysis following such injuries in the majority of cases is temporary, but in some cases, in addition to direct injury of the nerve, forcible traction from displaced bone fragments may damage the nerve for a considerable distance, making surgical repair of the nerve necessary but difficult. In healing of the fractured humerus the nerve may become embedded in callus, preventing regeneration of the nerve.

Another important example of direct injury to a nerve from fracture with traction on the nerve is that of the external popliteal (common peroneal) where it passes forward over the fibula. The extent and gravity of traction effects upon the nerve trunk in such cases may be difficult to estimate, making the required surgical treatment hard to determine, and often impossible to carry out.

## Incised Nerve Wounds

There is a marked difference in the effect of nerve wounds produced by sharp instruments and those caused by projectiles. Incised wounds are often caused by fragments of glass and these are similar in every respect to those produced by bayonets, knives, or other sharp weapons While other important structures (such as blood vessels, tendons, and muscles) also may be divided in such wounds, there is little destruction of tissue as a rule—certainly nothing comparable with wounds produced by gunshot and other projectiles The disinfection of such a wound is a simple procedure.

Incised wounds are the most frequent type of nerve injury in civilian life. There is a widespread tendency, among those not familiar with nerve injuries, to minimize the gravity of nerve impairment when a wound is inflicted by a sharp instrument Inability to close the eye or retract the corner of the mouth on the same side, following a stab wound in the region of the parotid, is unequivocal proof of division of the trunk of one or more important branches of the facial nerve. The loss of power to approximate the little finger to the ring finger in a stab wound of the wrist means that the ulnar nerve has been divided either partially or completely.

## SENSORY DISTURBANCE IN PERIPHERAL NERVE LESIONS

The area of sensory loss following nerve injury is by no means so consistent as the motor effect. Pollock has shown that there is much overlap in sensory fields supplied by various nerves. It is likewise believed that the denervated skin field has an attraction for sensory fibers growing from contiguous healthy nerves, the result being that the area of sensory loss, due to this overlap, may become much smaller than the original anesthetic field.

## INDICATIONS FOR OPERATION IN PERIPHERAL NERVE INJURIES

While the duration of the regenerative capacity of a divided nerve is not definitely known, it is generally believed that the earlier suture is performed under favorable conditions, the better the end-results will be. Delay in restoring the continuity of the nerve results in marked atrophy, periarticular fibrosis, and other effects which may permanently impair the results of suture. Much useful knowledge as to the effect of delay in suture of the nerve was acquired in World War I. This delay was occasioned chiefly by persistence of localized infection and to some extent by the conservative attitude toward nerve injuries arising from the inexperience of surgeons in the treatment of these lesions. Few cases · requiring nerve suture were operated on within six months after the injury was received. Misleading signs of regeneration, such as Tinel's phenomenon, were relied upon to determine nerve regeneration when, as a matter of fact, this sign was of very little practical value. Recoverability of nerves following injury was determined by delaying the operation, but in those lesions in which there was complete division of the nerve with no chance of spontaneous recovery, effects of long-continued denerva-

tion persisted as permanent residuals after nerve suture was finally done. It soon became evident in the treatment of nerve injuries that the lesion was usually worse than the clinical signs indicated and that definite knowledge as to the exact type of lesion was possible in many cases only by inspection of the nerve at exploration. This has very properly led to a more radical attitude toward exploration when there is complete paralysis of a peripheral nerve following injury.

It should be well established at the present time that when complete physiologic interruption of peripheral nerves follows gunshot wounds, the nerve should be explored as soon as the local condition will permit. Inasmuch as gunshot wounds of the extremities involve the main peripheral nerves in a high percentage of cases, careful examination for nerve injury should be made as soon as practicable after the patient comes under observation. The record of such examination may be brief, but it should show in every case whether there is evidence of nerve injury and what nerve or nerves are involved.

It has been found in treating war wounds that if the wound is closed tightly it often becomes infected; there are several reasons for this. The high-velocity projectiles produce extensive damage and destruction of tissue. Due to the exigencies of war and the large number of wounded, it is not always possible to give the painstaking care necessary to complete débridement of such wounds as is possible in the relatively few nerve injuries in civilian practice. War wounds may be contrasted with bullet wounds in civilian life where the velocity of the projectile is lower, producing less structural damage, and where sufficient time may be given for complete débridement and adequate disinfection of the wound at the time of primary treatment. There is no reason why the average bullet wound of an extremity with division of a

nerve in civilian life should not be disinfected, debrided, the nerve sutured, and the wound closed at operation, provided such operation is carried out before infection develops.

Infection is a contraindication to operation on nerve lesions. However, if infection has been eradicated the nerve may be repaired before the wound has completely healed. Infection as a complication of war wounds has been reduced greatly by chemotherapy and better surgical treatment, but chemotherapy should not be considered a substitute for proper surgical procedures nor adequate disinfection of the wound. Should infection develop it can be eradicated much more readily since the advent of chemotherapy. The prevailing practice in the primary treatment of gunshot wounds in warfare is to débride the wound and leave it open with the use of sulfanilamide or some other form of chemotherapy in the wound. It has been shown from animal experimentation that sulfanilamide freely applied along the course of the sciatic nerve in rabbits is followed by evidence of nerve damage, indicating that caution is necessary in using the drug on exposed nerves in the primary treatment of the wound.

If divided nerves are not sutured or their ends fixed at the primary operation for treatment of a wound, there is inevitable retraction of the nerve segments and neuroma formation. The retraction of the nerve ends and neuromas may be so extensive as to make approximation of the nerve extremely difficult at the secondary operation. The surgeon who conducts the primary treatment of wounds of the extremity is largely responsible for the ultimate results of treatment of many peripheral nerve injuries. Obviously, the best time to suture all divided nerves is as soon as practicable after injury. In civilian practice this can be done in nearly every case within the first few hours. There is little loss of nerve substance and suture can be made with little tension.

In the primary treatment of gunshot wounds of the extremities the débridement should be done carefully, not only to protect the injured nerve from further damage but also to avoid injury to other nerves that have not been wounded by the projectile. If a nerve is found divided the ends should be tied together with silk or tantalum wire and in some cases it may be practicable to do an immediate suture; however, extensive dissection of the nerve in order to perform a classic nerve suture would seem to be unwise at the time of primary treatment. It should always be determined whether there is nerve involvement before a cast is applied to an extremity.

## GENERAL OPERATIVE TECHNIC

### ANESTHESIA

General Anesthesia. General anesthesia is to be preferred for operations on peripheral nerves. The removal of a nerve from dense scar tissue, in the author's experience, has always been a painful procedure to the patient. While one may forecast the extent of operation in most cases, it often happens that in order to approximate the nerve segments for suture without tension, the nerve trunk must be mobilized for a distance much greater than originally contemplated. The procedure is time-consuming, and long incisions of the extremity are usually necessary. For instance, a wound of the ulnar nerve in the midforearm may require transposition of the nerve at the elbow and to do this the incision must be extended well along the arm and forearm.

Local Anesthesia. This may have slight advantages in permitting a wider use of faradic stimulation during operation, but this advantage is purchased at the expense of considerable strain on the morale of both patient and surgeon. The author has preferred ether administered intratrache-

ally but ether by ordinary inhalation is quite satisfactory. Avertin, supplemented by ether or sodium pentothal, for short operations may be used, but the average case in which there is marked scar formation, requiring extensive dissection, will be done more satisfactorily under ether anesthesia. The author has used continuous spinal anesthesia in a few selected cases for operation on nerves of the lower extremities and this type of anesthesia has proved adequate.

## SURGICAL EQUIPMENT

Operations on peripheral nerves require instruments and equipment suitable to the refined technic which this type of surgery demands. Sharp knives are an essential part of the equipment for dissection. Small tissue forceps, nerve hooks, and small self-retaining retractors are necessary for the refined operative technic. The electrosurgical unit and suction apparatus are now an indispensable part of neurosurgical equipment and are highly essential in operations on peripheral nerves. An inductorium is very satisfactory for stimulation of the nerve trunk at operation.

Recently there has been considerable discussion as to the best material for nerve suture. For many years the author has used arterial silk for suture of the epineurium and prevented retraction of the nerve ends by one penetrating relaxation suture of fine silk (formerly fine catgut) through the nerve about 1.5 cm. from either end.

Fine tantalum wire for nerve suture instead of arterial silk has been widely used in World War II. It is claimed by advocates of this suture material that it is less irritating than silk and better tolerated by the tissues. It is also pointed out that postoperative x-ray examination made immediately after suture, compared with later films, will determine whether the suture line has held. There is some merit in the latter claim for tantalum wire but the au-

thor has not been convinced it has any other advantages over fine silk as a suture material and there is reason to believe that metal sutures of any kind may interfere with postoperative physical therapy. One definite disadvantage of tantalum wire as it is supplied at present is its relative invisibility which makes its handling as a suture material quite difficult.

## POSITION AND DRAPING OF PATIENT ON TABLE

The position of the patient on the table should be such as to provide the maximum accessibility to the nerve to be exposed. The possibility of the need for an autogenous nerve transplant should be considered in placing the patient on the table and in arranging the drapes. In operation on nerves of the upper extremities, a board projecting from the side of the table to support the arm allows the extremity to be in such position as to give access to any of the main nerves. In operation on nerves of the lower extremity such as the sciatic or one of its constituents, the patient is placed face down on a shoulder support and the operative field so draped that the nerve may be explored for a considerable distance.

In draping the patient for operation on any nerve, allowance must be made for extension of the incision well above and below the level of the lesion. The draping should be so arranged as to determine the effect of faradic stimulation on muscle action for which the nerve is responsible. This is absolutely essential in lesions in which the nerve has not been completely divided. The drapes may be held in place with Michel clips.

## PREPARATION OF SKIN

Any of the accepted antiseptic solutions for preparation of the skin is satisfactory for operations on peripheral nerves. The author has generally used alcohol and io-

surgeon must determine whether direct approximation of the prepared nerve ends can be made without undesirable tension. Various methods for overcoming defects in divided nerves will be discussed in later paragraphs. It may be necessary to combine posture with transposition of the nerve before excision of the scarred nerve ends to determine whether the prepared ends can be satisfactorily approximated. If direct suture then seems improbable, the maneuver for gradual stretching of the nerve is indicated. The same situation arises when a long neuroma in continuity requires excision. Gradual stretching may be accomplished in this situation by excising the central portion of the neuroma and tying the residual neuromas together, followed by gradual stretching in the manner described for approximation of widely retracted neuromatous ends.

If the nerve is completely divided, the indications for specific surgical treatment are clear. On the other hand, if there is a fusiform neuroma or the nerve is partially divided, expert surgical judgment is required to determine just what type of operative procedure will offer the best results. In dealing with a neuroma in continuity it is frequently very difficult to decide whether a neurolysis is sufficient or whether the neuroma should be excised and direct suture made. It was common practice in World War I, when attempting to make a decision as to whether the neuroma should be excised or simply freed from scar, to inject saline solution under the covering of the neuroma in an effort to disclose the condition of its neural contents. In the author's experience this procedure is of doubtful value. On the whole, the investigation of a neuroma by all approved procedures often fails to give satisfactory information as to how much the scar formation will permanently obstruct regeneration. It is best to perform a neurolysis in doubtful cases with later resection and suture if the neurolysis fails to restore function. If there is response of the proper muscles to faradic stimulation applied above the neuroma, obviously it would appear unwise to excise the neuroma. However, if there is no response to faradic excitation and the neuroma is dense and firm, further information may be had by a longitudinal incision over the neuroma for direct inspection of the amount of scar tissue involving the neuraxes. Such a neuroma usually requires excision and direct suture of the nerve.

Gunshot wounds involving nerves result in marked fibrous-tissue formation and the scar is usually very dense. The nerve trunk is densely embedded in the adjacent muscles. This is true whether there has been complete division of the nerve or whether the injury has resulted in an intraneural hemorrhage with fusiform neuroma formation. The liberation of the nerve from scar tissue should be done most carefully to avoid injury to branches which may be leaving the nerve trunk in the scar-tissue area. Dissection for freeing the nerve for a considerable distance is often necessary. To accomplish this in the safest way it is always best to expose the nerve above and below the lesion, then proceed to the lesion itself. Oozing from scar tissue may be very troublesome but this can be controlled by the careful use of the electrosurgical unit and the application of fibrin foam. The control of bleeding is necessary not only for the protection of nerve branches during operation but at the completion of the operation there should be a dry field to minimize postoperative scar-tissue formation.

When there is partial severance of a nerve, provided it is not almost complete, every effort should be made to preserve the uninjured fibers. This usually requires, except in the sciatic, a longitudinal incision of the nerve trunk in order to mobilize the divided fibers, and this results in a loop of

the intact fibers after approximation of the divided segments. If the nerve trunk is almost entirely divided, it is better to make complete section and do a direct suture

### APPROXIMATION OF DIVIDED NERVES

Division of a nerve trunk always results in retraction of the nerve segments. If the injury is of such character as to permit early primary suture, the nerve segments may be approximated with little difficulty. However, if suture is delayed, neuromas form on each segment of the retracted nerve ends and these must be excised before suture is done.

Satisfactory approximation of nerves by delayed suture remains a considerable problem, particularly if there has been loss of nerve tissue such as results from gunshot wounds. It has been found from experience that there are a number of procedures which may be used to assist in the approximation of retracted nerve segments without excessive tension. The following procedures for relaxation of nerve segments may be mentioned: (1) Posture of the segments of the extremity, (2) immediate nerve stretching; (3) a combination of posture and gradual nerve stretching; (4) transposition of the nerve to a more direct course in combination with posture of the extremity; (5) a combination of posture, transposition, and gradual nerve stretching; (6) resection of bones of the extremity; (7) nerve grafts.

### POSTURE OF LIMB

Certain postures of an extremity in many cases will relax a nerve sufficiently to enable satisfactory approximation and will afford some relaxation in all cases. Flexion of the forearm shortens the distance which the median nerve travels. Palmar flexion of the wrist reduces tension on the median and ulnar nerves at this level. Approximation and direct suture of the ulnar and median nerves for lesions in the upper arm may be facilitated by elevation of the arm and approximating it to the chest. Proper posture of the extremity brings about greater relaxation of the sciatic and its main branches than is the case in any other peripheral nerve. Long defects in the sciatic nerve may be overcome by flexion of the leg.

### NERVE STRETCHING

Approximation of the prepared nerve ends for suture, when there has been only slight retraction, may be facilitated by gentle traction on the nerve segments. It is thought that 1 to 2 cm. may be gained by this maneuver, but this will often require dissection of the nerve segments to a considerable distance.

Gradual stretching of the nerve to bring about subsequent approximation without excessive tension is a valuable procedure when immediate approximation is impracticable. This method should be resorted to whenever the location of the nerve injury is such that relaxation and tension on the nerve are favorably affected by posture of the extremity. This maneuver for gaining distance is helpful in nearly all of the important peripheral nerves.

The combination of gradual stretching with transposition of the nerve may be used in overcoming defects of the ulnar, median, and musculospiral (radial).

Exposure of the divided nerve may show there is considerable retraction of the nerve segments and extensive neuroma formation on each of the nerve ends. It may be evident at once that, after excision of the neuromatous scar, approximation would be impossible, or, if accomplished, the tension would be so excessive as to interfere with regeneration through the suture line. In such cases the nerve may be gradually elongated by appropriate posture of the extremity for the maximum relaxation of the nerve, tying the neuromatous ends to-

gether as closely as possible with heavy silk sutures, and then, over a period of four weeks, stretching the nerve by a gradual return of the extremity to that position which causes the greatest tension.

With the extremity again in suitable posture to relax the nerve, the neuromas may be excised at a second operation and satisfactory approximation of the prepared nerve ends made. If it is necessary to keep the limb in a certain posture to effect sufficient relaxation for nerve suture, this posture must be maintained throughout the operation and for two weeks postoperatively. The extremity then should be very gradually extended over a period of two to three weeks. Inattention of an assistant during operation may result in a sudden change of position of the limb with tension on the suture line and even rupture.

There has been some objection to the method of gradual stretching to overcome defects of nerves to permit direct suture, but we do not believe that, if the limb is gradually extended after temporary suture, the nerve will be damaged. It is believed that during the period of stretching there is also a growth of the nerve segments which accounts in part for lengthening of the nerve. Some of the author's best results in nerve suture have followed gradual stretching of the nerve.

### TRANSPOSITION OF NERVES

· In certain nerves—notably the ulnar, median, and musculospiral (radial)—the combination of posture of the extremity with transposition of the nerve trunk to a more direct course will often bring about sufficient relaxation to enable the nerve to be sutured without unfavorable tension even though there may be considerable loss of nerve tissue. Lesions of the ulnar nerve in the arm or forearm may require the nerve to be shifted from its normal course behind the internal condyle to a position anterior to the condyle, then with the fore-arm in flexion a gain of about 3 to 4 cm. results.

It may be necessary in transposing the ulnar nerve, when there is a large defect, to sacrifice some of the branches to the forearm, particularly those to the flexor carpi ulnaris, in order to effect a satisfactory direct suture of the nerve trunk and thus restore the more important functions of sensation in the hand and action of the intrinsic hand muscles. However, every effort consistent with these more important objectives should be made to save the branches to the flexor digitorum profundus.

In extensive defects of the musculospiral (radial) it may be necessary to shift both the proximal and peripheral segments of the nerve from the normal course in the musculospiral groove to the inner side of the arm. This procedure with the forearm in flexion brings about considerable relaxation of the nerve.

The median nerve may be placed in a more superficial position by dividing the superficial head of the pronator radii teres. With the arm in flexion this transposition will gain some distance and often allow satisfactory suture.

### RESECTION OF BONES OF EXTREMITY

In combined lesions of the median and ulnar nerves in which it is impossible to secure direct approximation of nerve ends by conservative measures, resection of the humerus has been done. If the three larger nerves of the arm are divided and cannot be sutured, and if, in addition, there is division of the brachial artery with extensive muscle loss, in the author's opinion no form of surgical treatment will restore the lost innervation or give results of practical value. In such cases amputation of the arm is indicated.

There is a definite, though limited, field for resection of bone to make satisfactory nerve suture possible and it is usually to be preferred to nerve transplantation, but

it would be most inadvisable to resort to this unless it were impossible to approximate the nerve segments by less drastic measures. The author has seen no occasion for use of bone resection except in cases of high lesions of the median, ulnar, musculospiral (radial), and musculocutaneous, when more than one of these nerves were divided. Resection of the humerus has been used by the author in a small number of cases to permit approximation of nerve ends and the results obtained have not justified any great enthusiasm for this procedure.

## NERVE TRANSPLANTS

Transplantation of nerves was carefully studied from the experimental standpoint by Huber and his associates in the Army Laboratories during World War I. There does not appear to have been any important contribution to the subject since the publication of Huber's work. If nerve transplantation is done, autogenous transplants should be used. Cable autogenous transplants were suggested by Huber and were generally obtained from the musculocutaneous (superficial peroneal) nerve of the leg. Homologous transplants also have been used. These were formerly preserved in formalin. More recently, Weiss has suggested that dried, frozen homologous grafts might be used. It is possible in reconstruction hospitals in times of war to obtain homologous grafts and sometimes autogenous specimens of similar nerves for fresh transplants.

Insofar as the author knows, cable transplants, as suggested by Huber, were a complete failure in every case of clinical use. Some of the cable autogenous transplants were examined a few months after they had been applied to gaps in the nerves and there appeared to be some penetration of the axons into the proximal portion of the transplants for a short distance, but there was gradual incarceration of the regenerating fibers in dense scar tissue with no likelihood of regeneration continuing successfully through the entire length of the transplant.

From a clinical standpoint the use of transplants to repair defects in the larger peripheral nerves appears to be a failure and it is highly doubtful that any type of transplant will bring about functional recovery of practical value. The author has always considered clinical transplantation of larger peripheral nerves a futile procedure. In small nerves, such as the facial and those of the hand, the distance to be traversed by the transplant is short, nerves of suitable size can be obtained, and autogenous transplants would seem to have a field of some value here; but the situation in these small nerves is entirely different from those of other nerves such as the median or musculospiral (radial). In division of larger peripheral nerves, function can be restored only by direct suture.

## ANASTOMOSIS

Re-innervation of important muscles or muscle groups has been attempted by anastomosing a healthy nerve or one of its branches to the paralyzed nerve for the purpose of restoring the lost innervation. There have been some few experimental and clinical reports of this method. In poliomyelitis in which the anterior tibial (peroneal) has been destroyed, it has been proposed that the posterior tibial may be divided and sutured into the peripheral stumps of both the posterior and anterior tibial nerves. The author has attempted innervation of the axillary nerve by using a branch of the musculospiral (radial) supplying the upper head of the triceps. The assumption in transplantation of this type is that when a nerve is divided, the number of axis cylinders of the proximal segment is greatly multiplied in regeneration and that a small nerve might thereby be so enhanced in regenerative activity as to take

over the function of the larger paralyzed nerve with which it has been anastomosed. There is an experimental basis for this assumption but clinically it has proved to be discouraging, except in restoring motion to the face when the facial nerve has been paralyzed. Here, either the hypoglossal or spinal accessory is utilized for anastomosis with the peripheral stump of the facial, to innervate the paralyzed facial muscles.

## TECHNIC OF DIRECT SUTURE

It has been emphasized that exposure of the nerve should begin well above and below the level of the lesion. In this way, the lesion is more readily exposed and one can better protect branches and with greater safety remove the nerve from its bed of scar. Gentle handling of the nerve trunk is highly essential. The author has never used gauze for sponging the nerve, but he relies exclusively on cotton pledgets moistened in saline or Ringer's solution.

When the nerve segments have been completely dissected free, the scar tissue is removed from the neuromatous ends by holding the neuroma over cotton pledgets supported by the finger and making thin serial sections, with a sharp safety-razor blade at right angle to the trunk, beginning near the tip of the neuroma. The sections should be left attached by a small part of the sheath until the final section, showing healthy neuraxes, is made. With each section the nerve end should be carefully inspected for evidence of healthy neuraxes. A magnifying glass is useful in this connection.

As the sections approach normal nerve, bleeding from the nerve trunk appears. Scar tissue should be completely excised from both nerve segments and the exposed healthy neuraxes should be visible to the naked eye. The ends of the prepared nerve segments should be smooth and show no irregular projections of the neuraxes. Bleeding from the nerve ends should be controlled with moist cotton pledgets or preferably fibrin foam.

After all neuromatous scar tissue has been removed from the ends of the nerve segments and healthy neuraxes exposed, if there is tension a relaxation suture of fine silk is passed through the nerve trunk about 1.5 cm. from the ends of each segment. The nerve segments are then approximated and maintained in position by clamping the relaxation suture near the trunk with rubber-covered mosquito forceps while the sheath of the nerve is being sutured with arterial silk (Fig. 239).

After the epineural sutures have been placed on the exposed side, the unsutured portion of the epineurium is exposed by rotating the handles of the mosquito forceps holding the relaxation suture, and suture of the epineurium is then completed. The relaxation suture is then tied with sufficient force only to hold the ends in apposition without crowding the neuraxes. It has been asserted that a small gap between the sutured nerve ends is advantageous, at least experimentally, but such a gap would inevitably provide a situation conducive to scar-tissue formation. There may be some objection to the use of the relaxation suture through the nerve trunk and it should not be used if satisfactory approximation of the epineurium as well as its neural contents can be made otherwise. However, whatever may be the experience in laboratories, all human nerves are under varying degree of tension if the repair is delayed. If only the epineurium is sutured when any tension exists there will be retraction of its contents with formation of a clot, resulting in a fibrous tissue block which will militate against recovery of the nerve more than the effects of a relaxation suture through the nerve trunk which keeps the neuraxes approximated.

The approximation of the epineurium should be precise and there should be no

FIG. 240.* (*Top*) Transposition of musculospiral nerve to inner side of arm to permit approximation and suture. (*a*) Scar of gunshot wound, (*b*) distal segment of nerve exposed and removed from musculospiral groove, (*c*) course of nerve when transposed between brachialis anticus and biceps to inner side of arm. The usual neuromas are seen on proximal and distal ends of nerve. (*d*) Completed suture.

FIG 241. (*Middle*) Neurolysis of ulnar nerve and autogenous cable transplants to repair long defect of the median nerve. (*a*) Scar of wound, (*b*) exposure of median nerve, (*c*) further exposure of median, ulnar, and internal cutaneous nerves. The median is completely divided with marked separation of bulbous nerve ends. (*d*) Cutaneous branch of musculocutaneous nerve of leg is exposed to obtain a transplant. The transplants are transferred with fine sutures held in mosquito forceps, (*e*) 9: cm. defect with transplants sutured in position.

FIG. 242. (*Bottom*) Gunshot wound of thigh causing severe injury to sciatic nerve with development of a neuroma in continuity. (*a*) A long fusiform neuroma imbedded in dense scar so common in gunshot wounds, (*b*) nerve above and below lesion has been exposed, (*c*) cut section of neuroma shows few funiculi, (*d*) serial sections were continued until healthy nerve ends appeared, (*e*) suture of nerve in usual manner. One relaxation suture was used.

(Courtesy, Surg., Gynec., and Obstet., 78:113–124. Copyright, 1944, by The Surgical Publishing Co. of Chicago.)

PLATE III
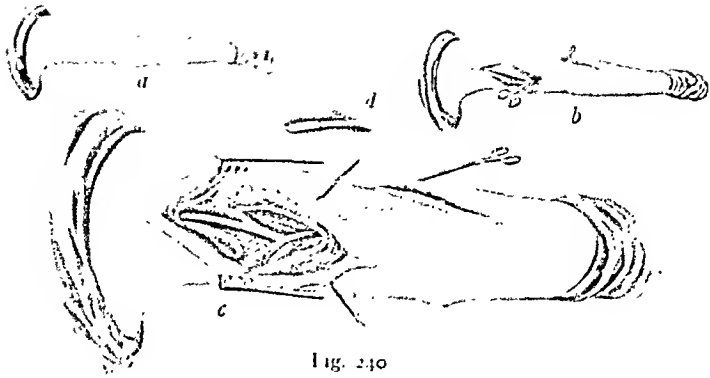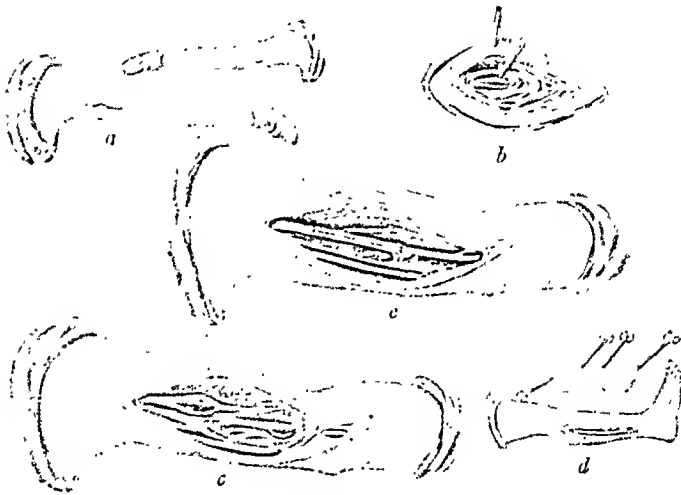
Fig. 240

Fig. 241

Fig. 242
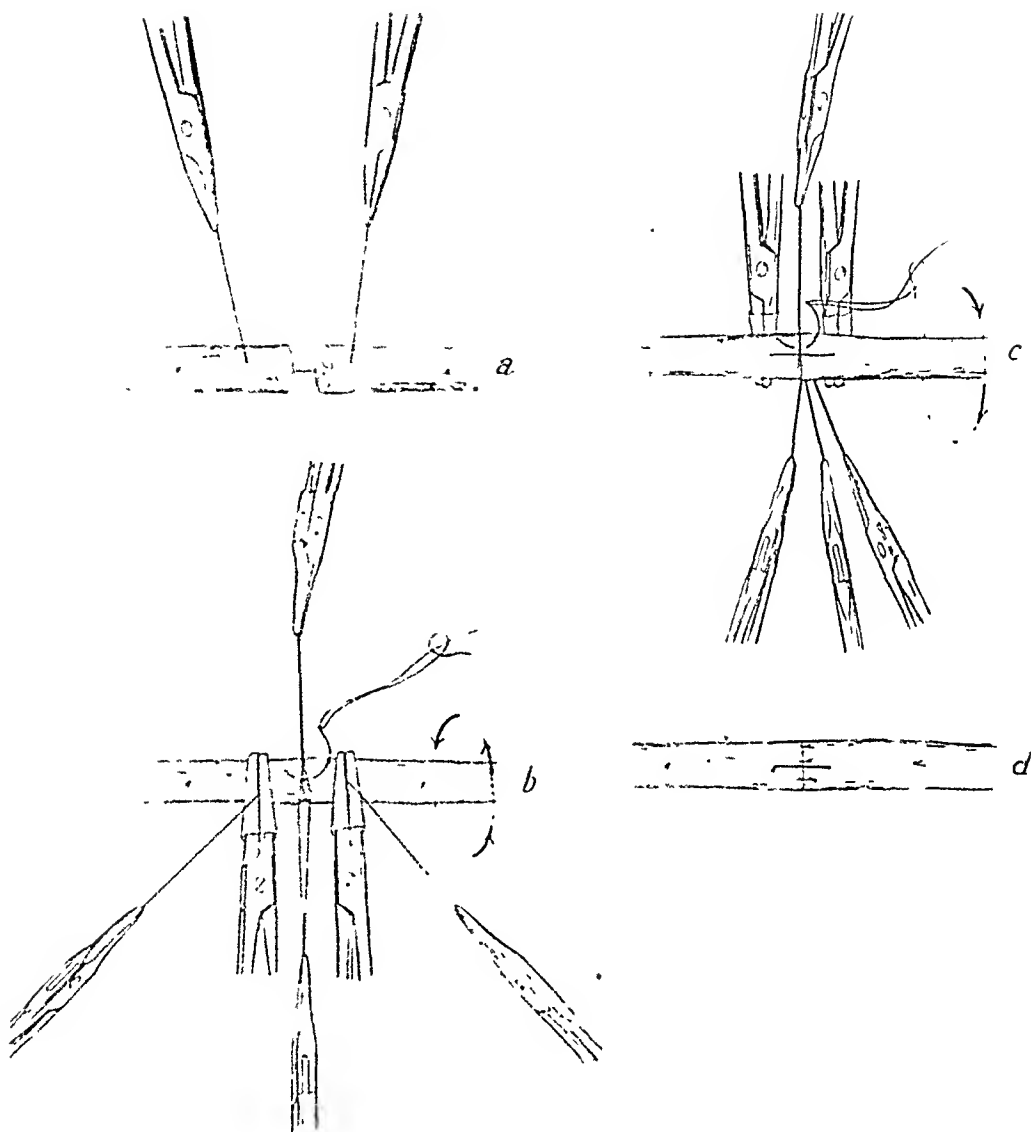
FIG. 239. Technic of direct nerve suture. (*a*) Silk knots are placed in epineurium of each nerve segment to indicate proper alignment. A tension suture of fine silk is used for approximation of nerve ends during suture. (*b*) By slight traction on the two ends of the tension suture, prepared ends of nerve segments may be. held in apposition. Each end of tension suture is then clamped with a rubber-covered mosquito forceps close to nerve to maintain approximation. Epineurium is carefully approximated for one-half circumference of nerve with arterial silk sutures. (*c*) Rotation of mosquito clamps will permit suture to be completed. (*d*) The completed suture. Tension suture is tied after all epineural sutures are placed. Nerve bundles should be brought in apposition without crowding, therefore amount of force used in tying tension suture should be precisely estimated.

projection of neuraxes between the sutures. Nerves, such as the median, ulnar, musculospiral (radial), external (peroneal) and internal (tibial) popliteal, will require six to eight sutures, while the sciatic may re-

Throughout the operation on peripheral nerves, drying of the exposed nerve trunk should be prevented by frequent applications of cotton pads moistened in Ringer's solution.
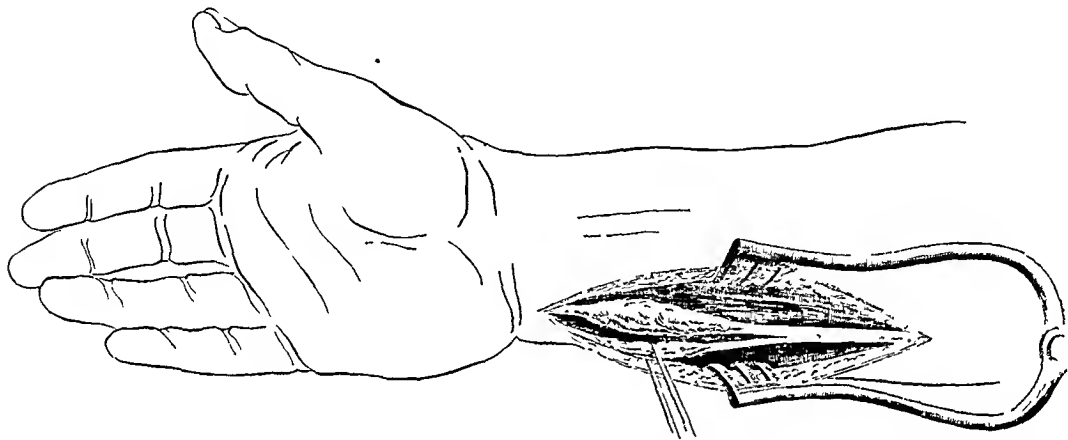


FIG. 243. Impermeable neuromas of dorsal and palmar branches of right ulnar nerve. Operation about three months after injury.
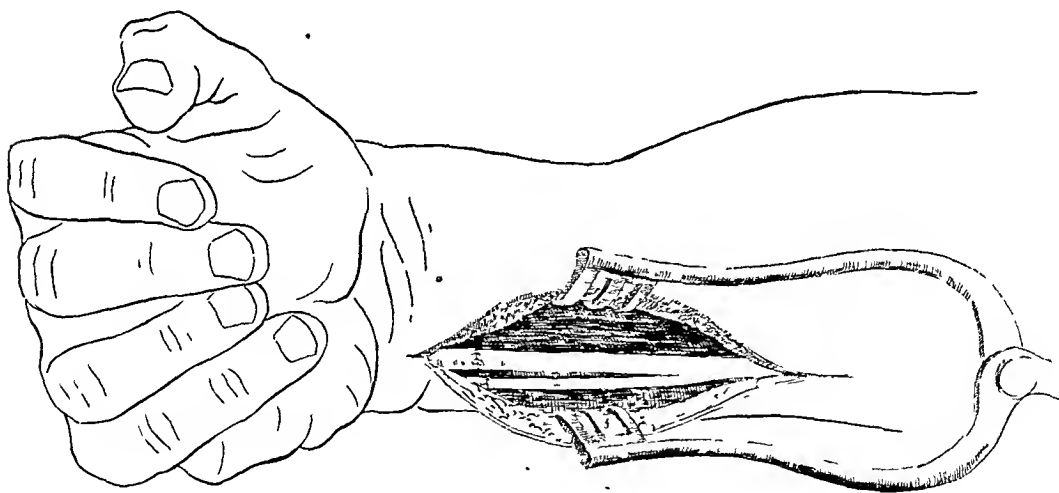


FIG. 244. Resection of neuromas found in Fig. 251, with direct suture of main branches of nerve. Wrist was kept in palmar flexion for three weeks after operation.

quire 12 to 15 for accurate approximation. Sutures in the epineurium should not penetrate the underlying neuraxes. In making the suture, jeweler's forceps will be very helpful in manipulating the delicate sheath.

Closure of wounds made for exposure of nerves should be made in layers using interrupted fine silk, that is, the fascia, if available, should be sutured and the skin closed without drainage. When there is a

tendency for the skin edges to invert we use upright mattress sutures. When there is a considerable scar, especially about the wrist, the skin sutures may be quite tense if the scar tissue is completely excised. It may be necessary in such cases to excise the cutaneous scar and do a full-thickness skin graft before the nerve is sutured, or it may be possible to suture the nerve and use a pedicled skin graft to close the wound at the same operation.

Protection of the suture line of peripheral nerves has been a subject of much study and many ingenious methods and numerous materials have been proposed. The purpose of protection of the suture line has been, primarily, to prevent the infiltration of scar tissue into and about the junction of the sutured segments. Among the materials proposed for this purpose have been flaps of fascia, cargile membrane, sections of arteries, tantalum foil, and more recently fibrin film.

It is believed by some that enveloping the nerve with a cuff of impermeable material not only inhibits scar-tissue formation but prevents confusion of the nerve pattern in regeneration and helps to direct the regenerating axones into their proper pathways. It is also claimed that neuroma formation is minimal at the site of suture when certain types of material, such as tantalum foil, are used for cuffs. It is generally believed that surrounding the nerve with flaps of fascia or arterial cuffs increases scar-tissue formation, and these materials have been abandoned. It is highly probable that many other substances suggested in this connection for the prevention of scar serve only to increase it. It has not been clearly demonstrated that slight neuroma formation after suture is harmful, nor does it seem reasonable to assume that the scar tissue about the trunk of the nerve is likely to invade the suture line, providing the epineurium has been carefully approximated. Furthermore, it is

questionable whether scar tissue about an accurately sutured nerve affects regeneration unfavorably, but intraneural scar definitely obstructs regeneration. The use of long impermeable cuffs such as tantalum about nerves, in the opinion of the author, may well have a tendency to interfere with blood supply at the site of suture, and the fact that such a tube may prevent neuroma formation is not necessarily an indication that the tube has facilitated regeneration.

Mediwar and Young, in 1940, proposed an ingenious method for end-to-end approximation of nerves by the use of a plasma cuff. Further investigation of coagulated plasma for this purpose has been carried out by Tarlov, who came to the conclusion that nerves requiring suture are usually under such tension that the tensile strength of the plasma cuff was not sufficient to hold the nerve segments in apposition until union occurred. In subsequent investigation Tarlov advocated the combination of the plasma cuff with a relaxation suture of fine tantalum wire. The application of coagulated plasma to the approximated nerve ends is a difficult and complicated procedure, requiring a special mold into which the plasma is poured. On the whole the process has not shown any advantage over the use of arterial silk in the repair of divided nerves and in view of its complicated use its value is doubtful in clinical cases.

The assertion that a tantalum foil cuff will prevent distortion of the nerve pattern is difficult to understand when it is well known that such distortion may take place in a serious lesion of the nerve even though it has not been divided and the epineurium is intact. For instance, distortion of the nerve pattern frequently occurs after a severe inflammatory lesion of the facial nerve or after contusion of the nerve when the epineurium is preserved. In such cases there is no infiltration of scar tissue from extraneural sources and the gross pattern

of the nerve is maintained. There are probably further objections to the use of tantalum foil nerve cuffs. The placing of a metallic foreign body on a nerve may cause irritation and perhaps causalgic pain. The presence of a metallic substance embedded in the tissue may seriously interfere with postoperative physical therapy, especially diathermy. Further studies of this material must be done before it can be recommended in the repair of injured peripheral nerves.

In the author's opinion the chances for maximum regeneration after satisfactory suture are best assured by careful hemostasis of the wound and returning the nerve to its normal bed between the muscles, or, if there has been dense scar, the nerve may be protected by a pedicled fat graft between the nerve trunk and surrounding scar.

### OPERATIVE TREATMENT OF LESIONS OF INDIVIDUAL NERVES

The incidence of injuries to individual nerves in the First World War was in the following order: (1) The sciatic and its branches, (2) the musculospiral (radial), (3) the median, and (4) the ulnar. Frazier, in his report of 2,390 cases, makes no report of injury to the axillary musculocutaneous or anterior crural (femoral) nerves, although these nerves were reported injured by the British and Germans and in Pollock and Davis' report of a series of United States Army cases. In the upper extremities the musculospiral (radial) shows the greatest incidence of injury in the American army. All series show a higher involvement of the external (peroneal) than the internal popliteal (tiibal), although injury to the sciatic trunk exceeds that of any other single nerve. In civilian occupations the median and ulnar nerves most frequently require operation because of injury.

### MUSCULOSPIRAL NERVE

The musculospiral (radial) arises from all the main spinal nerves forming the brachial plexus, traverses the axilla, and after coursing to the lateral surface of the humerus follows the musculospiral groove to the bend of the elbow where it lies between the brachialis anticus (brachialis) and the brachioradialis muscles. After reaching the level of the lateral epicondyle it divides into the superficial and deep branches, the latter being known as the posterior interosseus nerve (Fig. 245). This nerve passes around the radius to the back of the forearm between the two heads of the brachioradialis. The nerve is closely associated with the superior profunda (profunda brachialis) artery in its course around the humerus which makes dissection of the nerve at this level very tedious.

The musculospiral (radial) has a sensory branch which is of some importance. This is known as the superficial branch and at first it is lateral to the radial artery, lying beneath the brachioradialis. It leaves the trunk about 7 cm. above the wrist, passing beneath the tendon of the brachioradialis to the dorsal surface, and supplies the skin of the dorsolateral surface of the hand.

The musculospiral (radial) nerve is primarily one of extension, first of the forearm and then of the wrist and fingers. It assists in flexion of the forearm by its supply to the brachioradialis. In destruction of the nerve supply to the flexors of the wrist there may be substitute action performing flexion of the wrist through activity of the extensor brevis pollicis. The most common result of musculospiral injury is wristdrop. While the musculospiral is the largest nerve of the upper extremity, its motor function is not so vulnerable to injury over such a long distance as is the case in the median and ulnar. The motor function of the musculospiral terminates a short distance below the elbow in its supply to the extensors of the wrist, thumb,

and fingers. However, it is more subject to injury in fracture than any of the nerves of the upper extremity due to its close proximity to the shaft of the humerus The loss of power to extend the forearm is rela-

in the musculospiral groove on the lateral surface of the arm, it courses to a position much more medially at the bend in the elbow where it lies medial to the brachioradialis muscle Lesions below the elbow
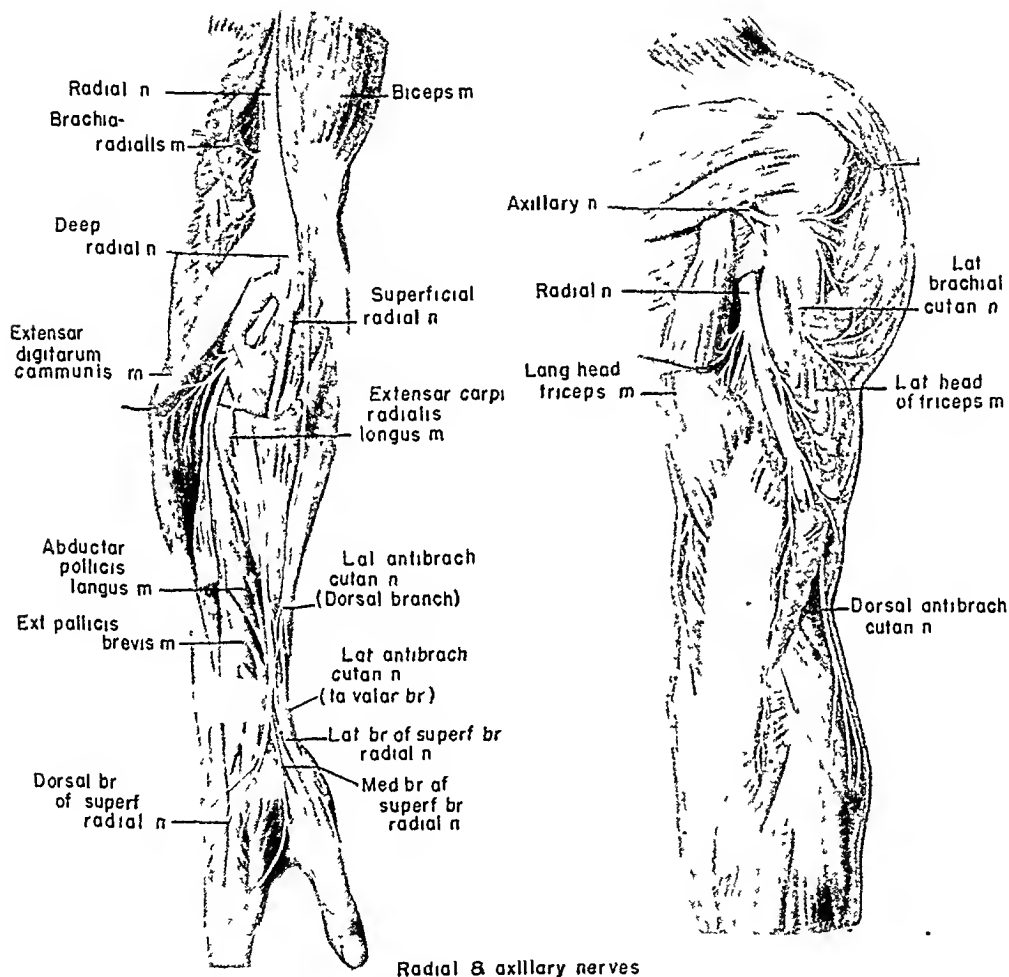


Fig. 245. Radial and axillary nerves (anatomic). (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux.)

tively infrequent in musculospiral lesions due to the fact the branch to the long head of the triceps leaves the nerve at a high level, thus escaping injury.

In exposing the nerve near the elbow, it should be remembered that although it lies

joint on the lateral surface of the arm present difficult problems due to the fact that the interosseus has split up into motor branches and that division of these branches is often at the point where they are inserted into the various muscles.

Surgical repair of nerves in such instances may be impossible.

When it is impossible to repair injury of the interosseus nerve due to gunshot wound because of scar tissue, very satis-factory substitution for the function of the paralyzed muscles to overcome wristdrop and loss of extension of the thumb and fingers may be brought about by tendon transplants. The tendon of the flexor carpi
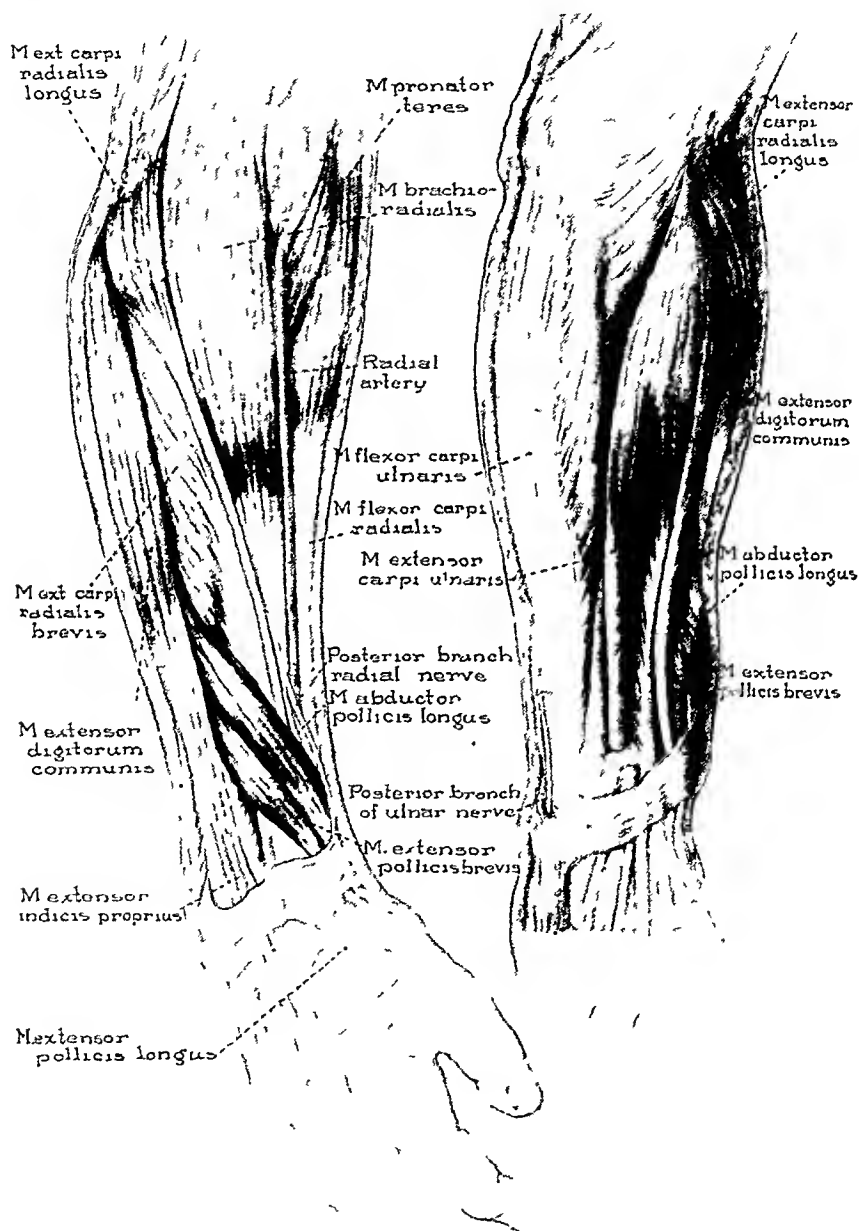


FIG. 246. The postero-lateral and postero-mesial views of the forearm show-ing the normal relationship of muscles and tendons.

radialis is divided at its insertion and carried under the brachioradialis to a dorsal position for insertion into the extensors of the thumb and tendon of the first finger. Through a separate incision on the medial surface of the forearm, the tendon of the flexor carpi ulnaris is divided and carried to a dorsal position for insertion into the tendons of the ring, middle, and little

Lesions of the nerve in the axilla can best be exposed by an incision made just mesial to the border of the pectoralis major muscle and extending over the insertion of this muscle, then parallel to the neurovascular bundle (Fig. 249) The skin flap is dissected down, giving access to all the nerves of the axilla. In lesions in the musculospiral groove and at the level
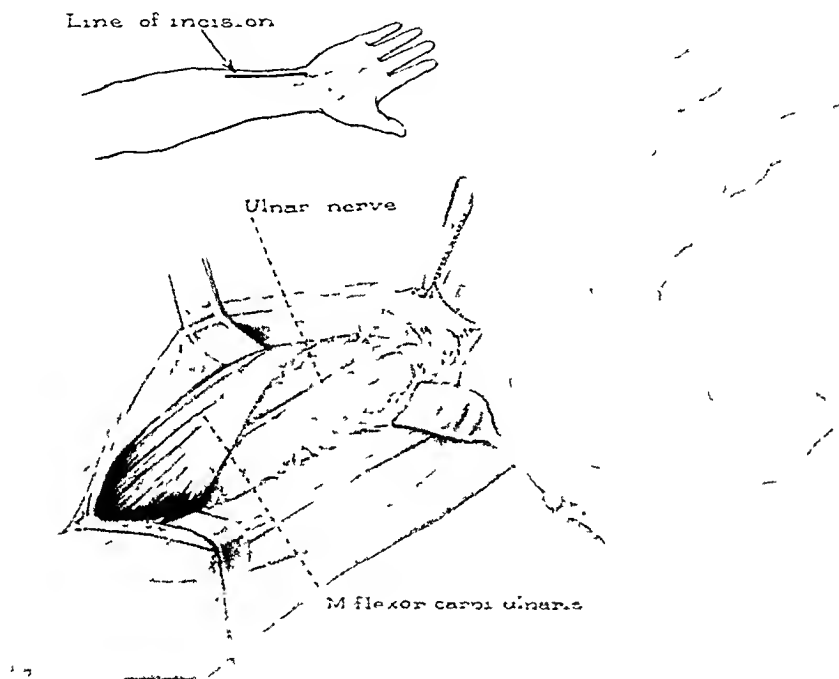


Fig. 247. The incision over the mesial aspect of the lower half of the ulna showing subfascial transfer of the tendon of the flexor carpi ulnaris. The oblique direction of this transfer provides for maximum function.

fingers. It is important that the degree of extension of the hand after suture of the tendons to the paralyzed extensors be sufficient to bring about the proper amount of extension without overstretching of the muscles. This requires that the bellies of the transplanted muscles be mobilized for some distance in the forearm. Flexion of the wrist after transplanting its principal tendons is affected by the palmaris longus assisted by the flexors of the fingers.

where the nerve begins its course around the humerus, exposure of the nerve may be most difficult. The nerve may be bound up in scar tissue, bleeding from the superior profunda artery is troublesome, the posture of the limb cannot be made entirely favorable, and the nerve must often be extensively mobilized toward the axilla and distally, well beyond the point where it leaves the musculospiral groove. It is sometimes found that due to associated com-

Labels in figure A':
M. extensor carpi radialis longus
M. extensor carpi radialis brevis
M. brachio-radialis
m. flexor carpi radialis
M. extensor indicis proprius
M. extensor pollicis longus
M. extensor pollicis brevis
M. abductor pollicis longus

Labels in figure B:
M. pronator teres
M. brachio radialis
M. ext. carpi radialis brevis
M. ext. carpi radialis longus

Labels in figure C:
M. flexor carpi ulnaris
Extensor digitorum communis

Labels in figure A:
Posterior branch radial nerve
Line of incision

Fig. 248. A. The "J" shaped incision over the dorso-radial aspect of the forearm and wrist.

A'. The method of transfer of the tendons of the flexor carpi radialis and the flexor carpi ulnaris to the extensor tendons of the fingers and thumb; also, transfer of the tendon of the pronator radii teres to. the radial extensors of the wrist.

B and C. The technique of transfer of the tendons and the method of fixation.

pound fracture of the humerus the nerve is attenuated and densely scarred over a considerable distance. Approximation of healthy nerve ends in the musculospiral groove under such circumstances is manifestly impossible. It is necessary in cases when extensive resection of the scarred nerve is required that the proximal end be transposed to a course mesial to the humerus and the distal end brought to the cord is formed by the junction of the eighth cervical and first thoracic nerves principally. The distribution of the branches arising from the outer roots is very similar to those of the musculocutaneous nerve which leaves the trunk formed by the fifth and sixth cervicals, immediately above the origin of the outer head of the median As the nerve courses through the arm it is the first lateral to the
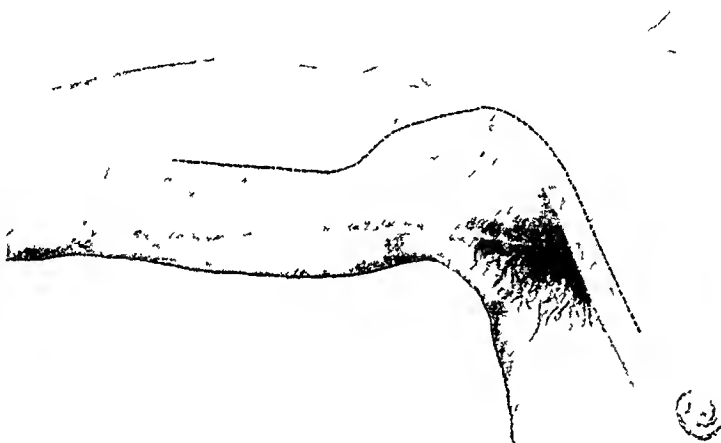


FIG. 249. Incision for exposure of high lesions of musculospiral, median, and ulnar nerves. It is often necessary to divide tendon of pectoralis major muscle. Incision is well away from axilla. Should approximation of arm to chest be necessary to relieve tension on nerve during operation, skin incision is still accessible and may be readily sutured. This incision may be intersected by another passing toward or even over clavicle in a case requiring higher exploration of brachial plexus.

inner surface of the arm between the brachialis and the biceps. Then with the forearm in flexion and the arm approximated to the chest, sufficient relaxation may often be obtained to secure satisfactory approximation, which otherwise would be impossible.

## MEDIAN NERVE

The median nerve is formed by the outer and inner cords of the brachial plexus. The outer cord arises from the sixth and seventh cervical roots whereas the inner brachial artery but rather close to the inner side of the artery at the bend of the elbow The median normally supplies no muscles of the arm except perhaps occasionally a branch to the brachialis

In the forearm the median supplies all the superficial muscles on the anterior part of the arm except the flexor carpi ulnaris. It also supplies all the deep muscles on the front of the forearm except the flexor profundus digitorum, three-fourths of this muscle being supplied by the ulnar nerve. The median nerve in the palm of the hand

is of great importance, being largely responsible for action of the thumb, so essential to dexterous use of the hand, and for important sensory function. Among the more important muscles responsible for motor function of the thumb may be mentioned the abductor pollicis, superficial head of the flexor brevis pollicis, and opponens. The median nerve also supplies the lumbricales of the first and second fingers. Whereas low-forearm lesions involving the musculospiral (radial) nerve are of little motor importance, injury to the median nerve throughout its extent may result in considerable disability. Furthermore, its sensory supply is of great importance in the lateral surface of the palm and palmar surface of the thumb and first three fingers.

Exposure of high lesions of the median nerve is best accomplished through an incision similar to that described for lesions of the musculospiral (Fig. 249). By this incision the skin of the axilla is avoided and the lower part of the plexus may be exposed without great difficulty. Should it become necessary to mobilize the nerve to the middle of the forearm, this can be done by extending the incision along the course of the neurovascular bundle. When the nerve reaches the elbow it lies between the two ends of the pronator radii teres and at this junction important muscle branches are given off. Below the elbow the nerve pursues a straight course, almost in the center of the plane of the forearm. It passes behind the carpal ligament and enters the palm of the hand, then breaks up into branches to the intrinsic hand muscles. Because of its straight course, little relaxation can be obtained by transposition of the nerve in the arm. However, by dividing the superficial head of the pronator teres which allows the nerve to assume a more direct course, and with the forearm in flexion, a short defect may be overcome.

The nerve is frequently divided just above the wrist joint by glass or knife wounds. With such injury there may be division of the ulnar nerve, the arteries, and important flexor tendons. In repair of injuries of this type by those not experienced in surgery of the nerves, errors due to confusion of nerves with tendons often result. Furthermore, in penetrating wounds of the palm of the hand, mesial to the base of the first metacarpal bone, the unfamiliarity of the operator with the structures in this location may lead him to disregard the nerve injury at the primary operation (Fig. 258).

Injury to the median in the palm may result from breaking of porcelain faucet handles when the latter is turned with force. This interesting injury may involve all the motor and sensory branches of the nerve at this level. The most satisfactory and opportune time to repair such injury is when it receives primary treatment (Fig. 252). The operation is somewhat more difficult than the average nerve operation but satisfactory repair can be made by those familiar with this type of nerve surgery. Should the injury not be repaired at the time of primary treatment of the wound it may not be possible at secondary operation to approximate the divided nerves. In such case, an autogenous graft from a branch of the superficial peroneal should be used with a fair chance of successful results.

A very troublesome injury, particularly in certain occupations, is division of one of the digital branches of either the median or ulnar. One case: an obstetrician had lost sensation in the tip of the left index finger and was therefore greatly handicapped until regeneration of the nerve had taken place after suture.

Occasionally the nerve is partially divided and a painful neuroma develops on one of the digital branches. Resection and suture should be done in such a case.

Painful lesions of the median nerve are not uncommon and are far more frequent than those of the musculospiral (radial) and ulnar. The author has seen a severe

PLATE IV
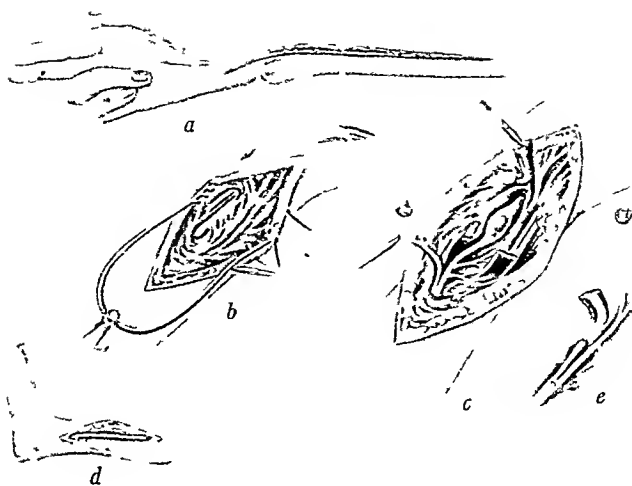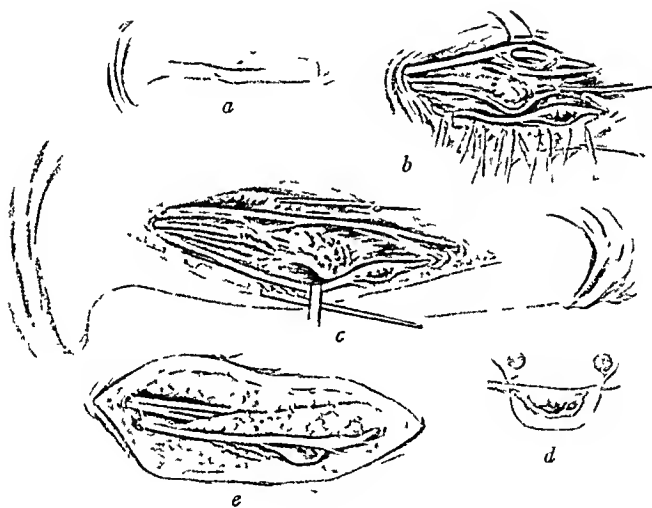


Fig 250



Fig. 251

FIG. 250 (*Top*) (*a*) Division of ulnar nerve at wrist with fracture of ulna by shell fragments Incision for exposure shown. (*b*) Dense scar involving nerves and muscles. (*c*) Dorsal branch of ulnar has been completely divided and a large impermeable neuroma is shown on palmar branch. After preparation of nerve for suture, a gap of 4.5 cm. was present, and ends could not be approximated. (*d*) Graft from musculocutaneous of leg was used for transplantation. (*e*) Grafts are shown in position. In small nerves such as the ulnar after its bifurcation, it would seem that autogenous grafts would have a definite field when direct approximation cannot be secured.

FIG. 251. (*Bottom*) Large lateral neuroma of left ulnar nerve. (*a*) Line of incision. (*b*) Exposure of median and ulnar nerves. (*c*) Median nerve is intact. (*d*) Lateral neuroma involving so much of the nerve that it did not seem feasible to attempt to save the few fibers remaining intact. Neuroma was completely excised. Funiculi of healthy nerve end after excision of neuroma are shown. (*e*) Nerve was removed from its normal bed and shifted to an anterior position to gain distance Branches to forearm muscles were protected in transposition.

median causalgia from the error, at primary treatment, of suturing the proximal segment of the nerve to the palmaris longus. Release of this unfortunate combination and suturing the proximal to the distal end of the nerve was followed by prompt and complete relief of pain.

Causalgia may be a frequent complication of incomplete median lesions. Causalgic lesions of the median nerve are difficult to relieve, and many of them are associated with marked sympathetic irritation causing excessive sweating, cold hand, and other signs of sympathetic disturbance. In these cases, injection of the second and third thoracic ganglia with novocaine solution is indicated, and, if this gives temporary relief, the injection should be followed by a preganglionic sympathectomy of the second and third thoracic ganglia. It is believed by some (notably Mayfield) that causalgia, even when there is absence of the usual effects of marked sympathetic disturbance, may be helped by injection of appropriate paravertebral ganglia.

## ULNAR NERVE

The ulnar nerve is smaller than either the median or musculospiral (radial). It contains fibers from the eighth cervical and the first thoracic, some from the seventh cervical, and a variable supply from the second thoracic. It arises from the inner cord of the brachial plexus. There are no branches from this nerve to the muscles in the arm but its motor innervation to the muscles of the forearm and hand is most important. Its sensory distribution is not confined to the palm of the hand as is that of the median nerve, but extends to the dorsum of the hand through a branch of the nerve which leaves the main trunk just above the styloid process. In its course through the arm it lies on the median side of the brachial artery, from which it diverges to pass through the intermuscular septum and behind the internal

epicondyle. It enters the forearm between the two heads of the flexor carpi ulnaris and descends along the ulnar side of the forearm lying upon the flexor digitorum profundus, to which muscle it gives three-fourths its supply.

The ulnar nerve divides into its terminal branches a few centimeters above the wrist joint. Its deep palmar branch is predominantly motor in function, innervating all the interossei, the adductor pollicis, the deep head of the flexor pollicis brevis, and also giving a branch to the fourth lumbrical. The origin of the ulnar, arising as it does from the inner cord of the brachial plexus along with the mesial head of the median, indicates the overlapping in the anatomic distribution of these two nerves. The ulnar is predominantly a motor nerve of the fingers in so far as fine movements are concerned, whereas the median takes over the most important motor innervation of the thumb. Lesions of the trunk of the ulnar nerve at any level cause loss of power of lateral movements of the fingers and inability to approximate the thumb firmly to the lateral surface of the hand, and it produces loss of power to extend the distal phalanges of the ring and little fingers. Furthermore, denervation from ulnar lesions causes a marked atrophy of the interossei with abnormal prominence of the metacarpal bones. The alteration in appearance of the hand is quite conspicuous, with the little and ring fingers assuming a posture known as "ulnar griffe." The atrophy of the interossei following complete ulnar interruption causes marked disability and the patient seldom recovers the ability to superimpose the little finger on the palmar surface of the ring finger. The grip is weak due to the loss of power of the interossei which assists in flexion of the proximal phalanges.

It is not rare at exploration following primary operative treatment of a wound at the wrist joint to find the ulnar nerve has

not been properly identified, with the result that the proximal end·of the ulnar has been sutured to the distal end of the flexor carpi ulnaris tendon. This unfortunate error may cause severe pain. When there

course for transposition or rerouting from its position posterior to the internal condyle to a more direct course on the anterior surface of the forearm. With this transposition and the forearm in flexion, consid-
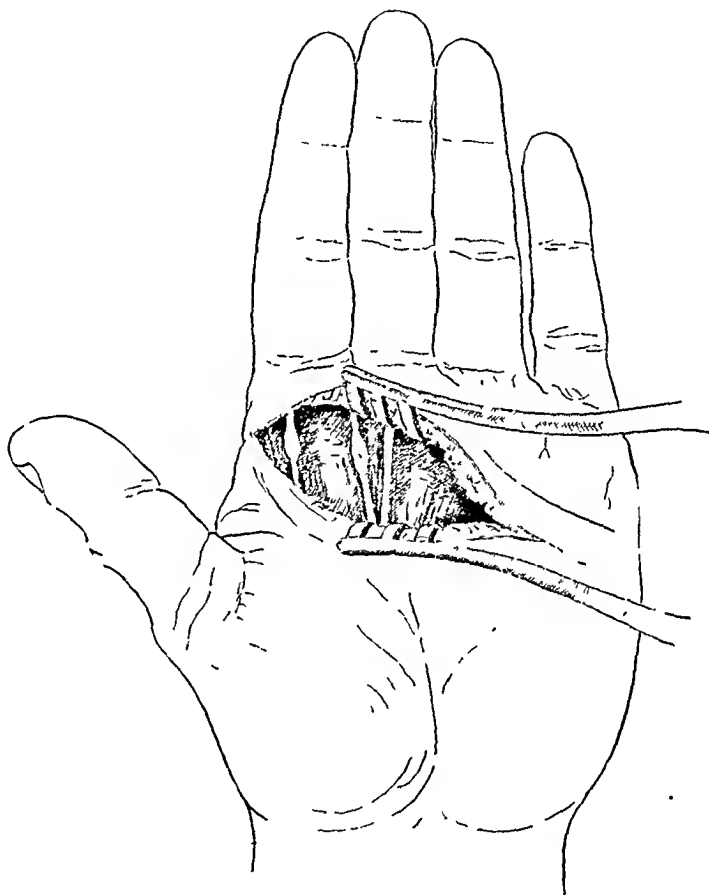


FIG. 252. Division of sensory branches of the median to left index finger. The neuromas were quite painful, which is often the case when small nerves in the hand are injured. Complete excision of neuromas and direct suture of the two small nerves was done without difficulty.

is the slightest doubt that all structures in the field of injury have been properly identified at the time of primary treatment, the author invariably explores cases of nerve injury. The findings revealed at exploration have justified this practice.

The ulnar nerve pursues a very favorable

erable relaxation of the nerve will be obtained. Flexion of the arm in ulnar lesions with the nerve in its normal position increases tension on the nerve. The articular branches of the nerve nearly always are sacrificed in transposition but it is usually possible to spare the motor branches, the

highest of which are those to the flexor carpi ulnaris. When extreme flexion of the forearm is necessary after transposition in fundus digitorum, to restore the more important ulnar function in the hand. In one such case in which this sacrifice was neces-



Nerves of brachial plexus
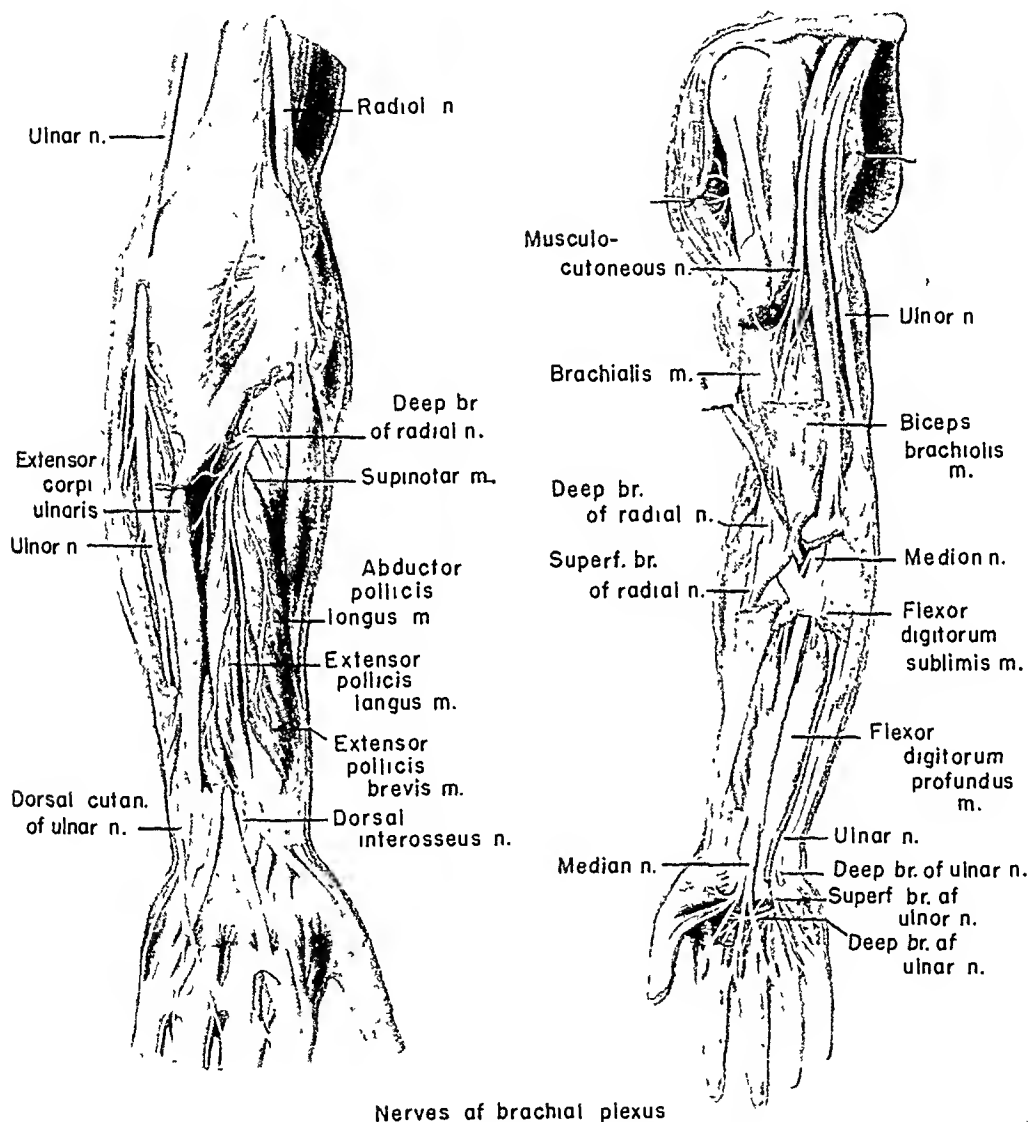
FIG. 253. Nerves of brachial plexus (anatomic). (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux.)

order to approximate the nerve ends for direct suture, it is usually necessary to sacrifice the branch to the flexor carpi ulnaris and occasionally those to the flexor pro- sary, it had been determined prior to operation that the median had taken over the entire supply to the flexor profundus digitorum.
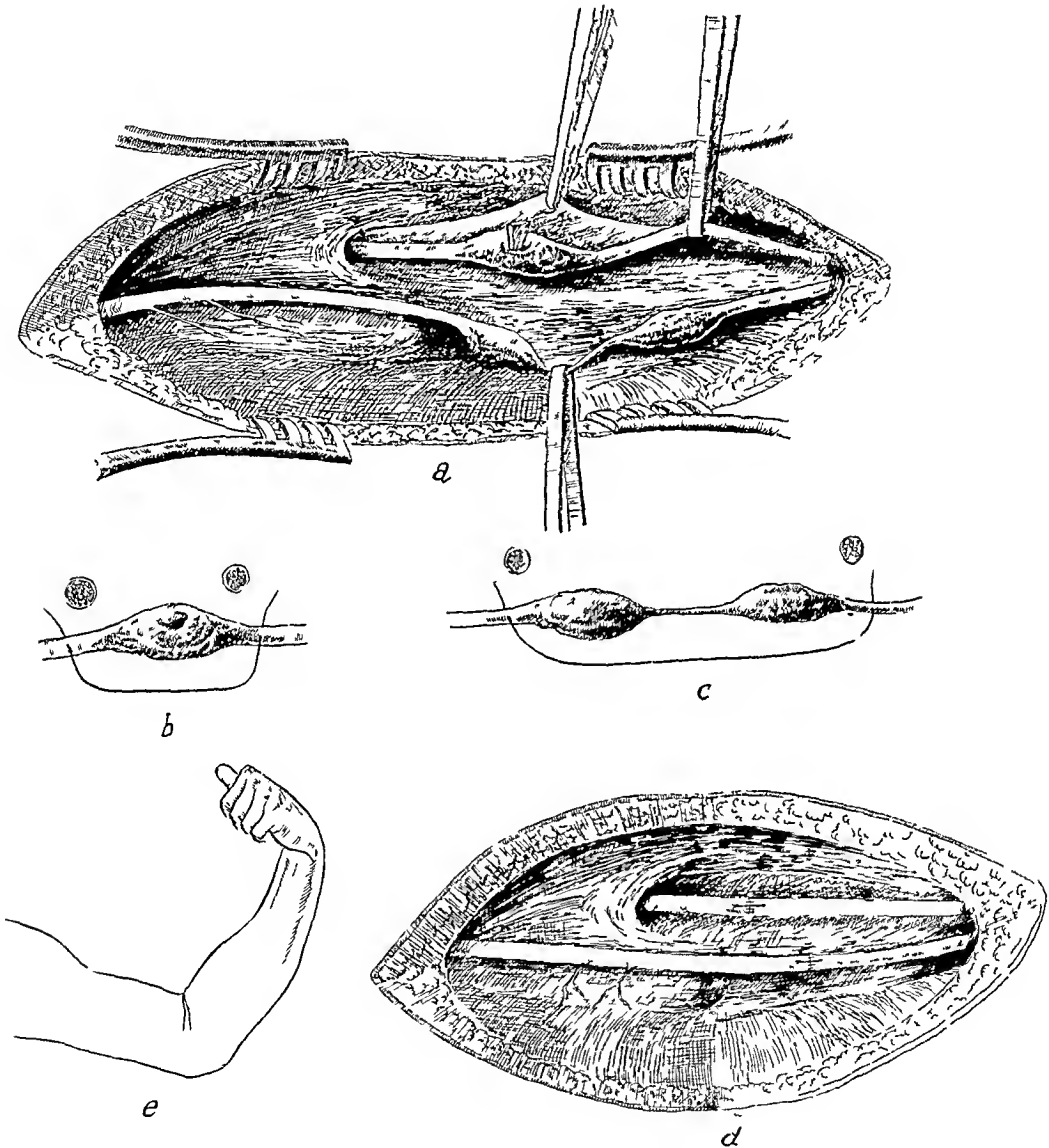
Fɪɢ 254. Injury to left median and ulnar nerves at elbow, associated with extensive bone fracture. (a) A spicule of bone was driven into median nerve, causing an imperme-able neuroma which was excised and direct suture was done. (b) Section of median nerve showing neuroma and cavity left after removal of spicule of bone. (c) Ulnar nerve was completely divided and there was extensive neuroma formation on each segment. (d) Ulnar nerve was transposed to a position anterior to internal condyle. Satisfactory ap-proximation required use of a tension suture. (e) Arm was maintained in flexion by a molded plaster splint for three weeks, then gradually extended.

COMBINED LESIONS OF MEDIAN
AND ULNAR NERVES

Combined lesions of the median and ulnar are quite frequent and may be produced at any level but in civilian life they are often caused by laceration of the palmar surface of the wrist. The appearance that has been described as "ape hand." If a lesion of the ulnar nerve is proximal to the branch supplying the flexor carpi ulnaris, flexion of the wrist is accompanied by deviation of
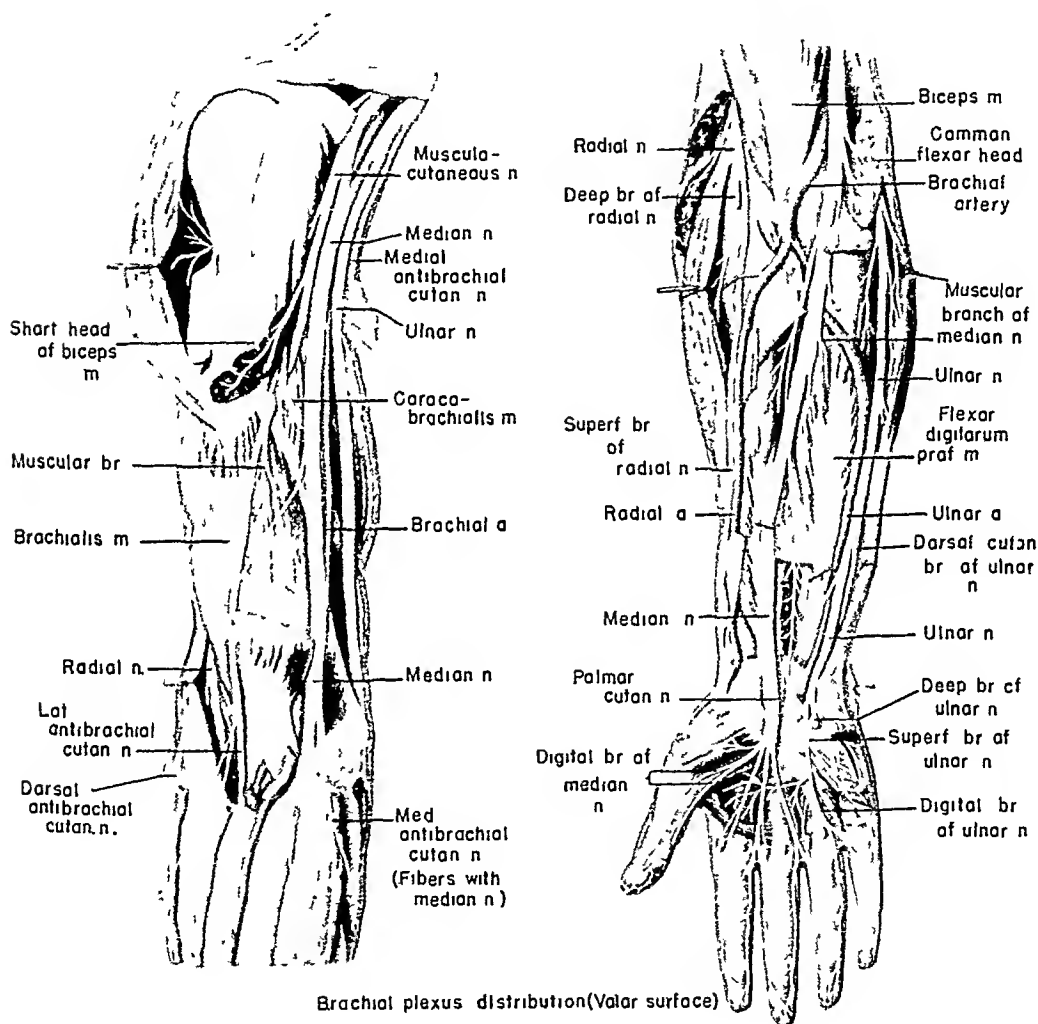


FIG. 255. Brachial plexus distribution (volar surface) (Anatomic.) (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux.)

are often caused by laceration of the palmar surface of the wrist. The appearance of the hand is greatly altered when both nerves are injured. There is marked atrophy of the palm of the hand which ac-

the wrist to the lateral side. If the median alone is injured at this level, the unopposed action of the flexor carpi ulnaris may cause a deviation to the ulnar side. In many lesions just above the wrist joint the

volar branch of the ulnar nerve is divided without injury to the dorsal branch. It is very important, therefore, in making the dissection of the nerve, in lacerations of the flexor surface of the wrist, to protect the branch which is intact.

Anesthesia in the hand and fingers re-

vical nerves. It supplies the coracobrachialis, biceps, and the greater part of the brachialis. It continues down the arm and forearm as a sensory nerve and presents many anomalies. The musculocutaneous nerve supplies the primary flexors of the forearm, but, when it is divided, flexion of
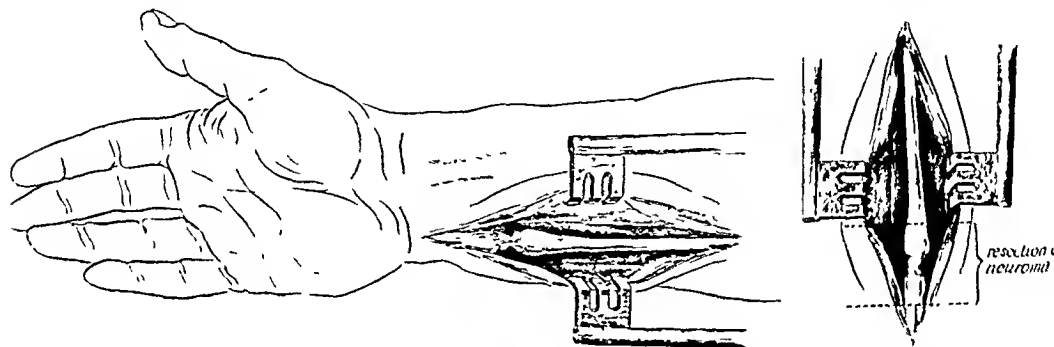


FIG. 256. Division of right ulnar nerve by glass just above its bifurcation. Appearance of nerve seven months after injury: Large neuroma developed in proximal segment. (a) Resection of the neuroma leaves a gap of about 3 cm. (Courtesy, Surg., Gynec., and Obstet., 78:113-124.)
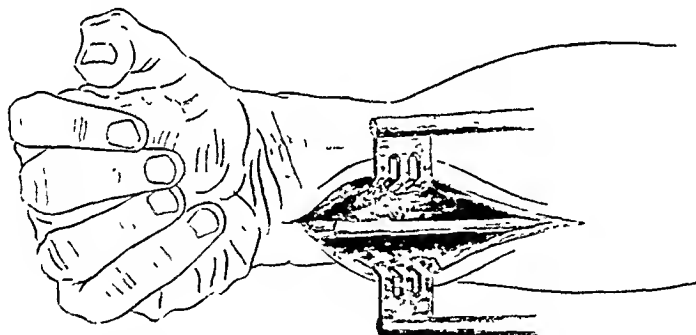


FIG. 257. Completed suture with hand in palmar flexion. (Courtesy, Surg., Gynec., and Obstet., 78:113-124.)

sulting from injury to the sensory branches of the ulnar and median nerves constitutes a real disability and restoration of sensory function is of utmost importance.

## MUSCULOCUTANEOUS NERVE

This nerve arises from the external cord of the brachial plexus along with the lateral head of the median, its fibers being derived from the fifth, sixth, and seventh cer-

the forearm may be accomplished by the action of the brachioradialis, supplied by the musculospiral. It is not rare to find all the four main nerves of the upper extremity paralyzed by extensive gunshot injury when the lesion is high on the arm.

## FEMORAL NERVE

This is the largest nerve of the lumbar plexus. It arises from the second to the

fourth lumbar nerves and lies in the groove between the psoas and the iliacus muscles, covered by the lateral border of the former. It is an important motor nerve to the anterior muscles of the thigh and is entirely responsible for extension of the leg. This nerve is closely associated with the femoral artery and vein, and injury to the nerve is most likely accompanied by injury to these



FIG. 258. Partial division of left median nerve by glass. There is practically no loss of nerve substance. (a) Y-shaped laceration of wrist; no tendons were divided. (b) Suture of divided portion of nerve performed a few hours after injury. (Courtesy, Surg., Gynec., and Obstet., 78:113–124.)

important vessels. Pollock reported the only cases (four) of a femoral-nerve injury in the United States Army Hospitals during the First World War. It is probable that many such injuries on the battlefield were fatal due to hemorrhage from the divided femoral vessels.

The femoral nerve breaks up into its branches at a rather high level, and, unless it is divided as high as Poupart's ligament, some of the branches are likely to escape injury. Division of the trunk, however, results in inability to extend the leg. One of its sensory branches—the saphenous—extends down the inner side of the thigh and leg to the medial border of the foot.

In exposing the trunk of the femoral nerve, the relationship of the nerve to the femoral artery and vein should be kept in mind. The artery occupies the position between the vein and nerve, the latter being lateral to both vessels.

### OBTURATOR NERVE

The obturator is primarily a motor nerve. There were no reports of injury of this nerve in World War I, nor has the author had such a case in civilian practice. Resection of the nerve has sometimes been done for spasticity of the adductors of the thigh.

### SCIATIC NERVE

The sciatic nerve receives fibers from the greater part of the sacral plexus and it is the largest nerve of the body, being a centimeter or more in diameter where it leaves the pelvis and increasing in size in the lower part of the gluteus maximus.

It has two main constituents—the internal (tibial) and external (peroneal) popliteal. The division of the trunk into these two nerves is usually quite evident in the midportion of the thigh, but may be traced higher, and the level of division is somewhat inconstant. At the level of the hip joint it lies anterior to the pyriformis muscle and as it traverses the thigh it takes a vertical course. It supplies all the muscles which flex the leg on the thigh but some of these branches arise above the level of the pyriformis muscle, therefore they usually escape injury. As a result one seldom sees a patient unable to flex the leg on the thigh in sciatic lesions, due to the fact that the branch to the semitendinosus usually leaves the trunk at a high level so that power of flexion of the leg, though weak, is retained. Lesions above the level

of the branch of the semitendinosus may involve important structures of the pelvis and often are fatal.

The nerve passes down the thigh posteriorly, being covered by the biceps. The internal (tibial) popliteal is the larger terminal branch of the sciatic and contin-

The sciatic nerve supplies sensation to the posterior surface of the thigh and to all of the leg except that which arises from the saphenous branch of the femoral.

Just above the popliteal space the two main trunks of the nerve begin to diverge The external popliteal (common peroneal)
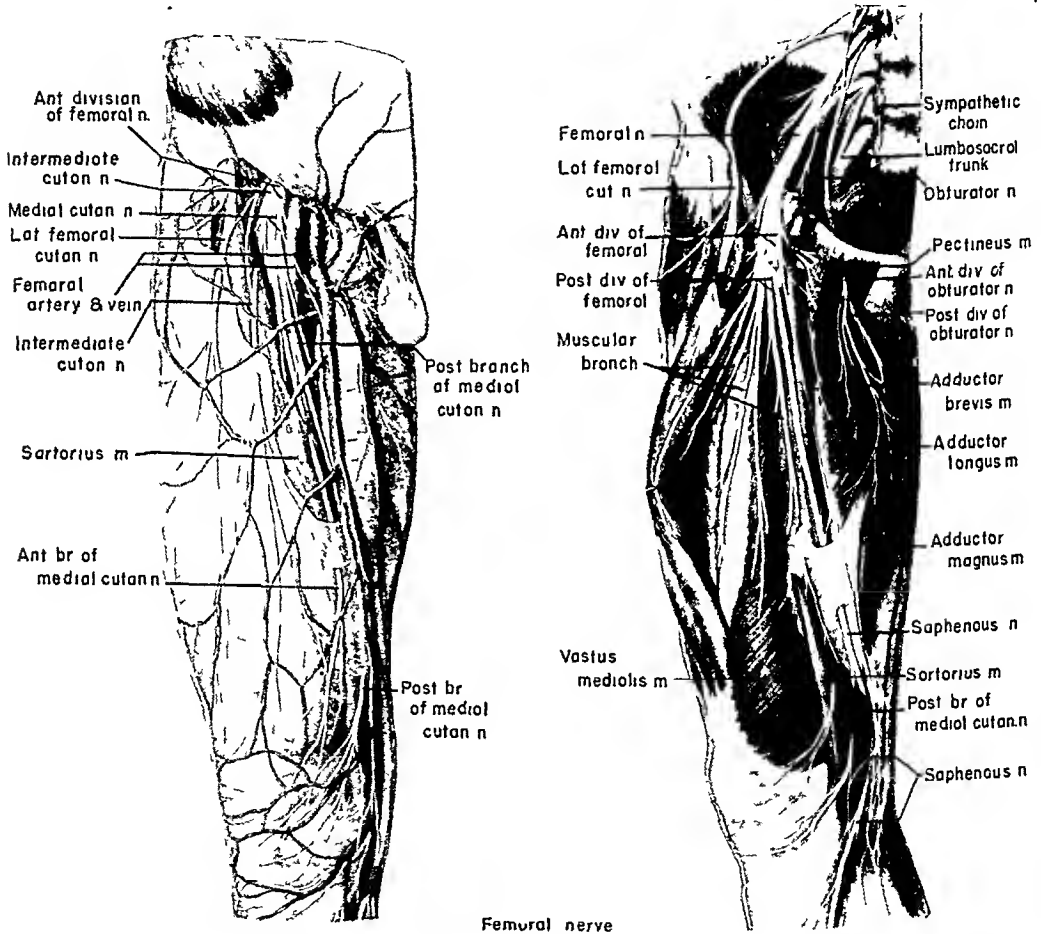


FIG 259. Femoral nerve (anatomic). (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux.)

ues in the same direction with the trunk— through the popliteal fossa, lateral to and behind the popliteal vein. As the popliteal artery divides, the nerve follows the posterior tibial artery, being lateral to this vessel. It is responsible for plantar and internal flexion of the foot.

which is the smaller of the two nerves passes to the lateral surface of the knee along the medial border of the biceps tendon and crosses the fibula just below its head, where it divides into two branches, the superficial and deep peroneal nerves The former supplies the peronei muscles

and the latter supplies the dorsiflexors of the foot and toes.

The sciatic and its two main trunks are more frequently injured in warfare than any of the peripheral nerves. Injury to the internal popliteal (tibial) nerve results in inability to perform planter flexion of the

cause extensive damage over a long segment of the nerve.

High lesions of the sciatic nerve are exposed by a curved incision beginning on the lateral surface of the buttocks and curving toward the midline (Fig. 261) It may be necessary to divide the tendon of
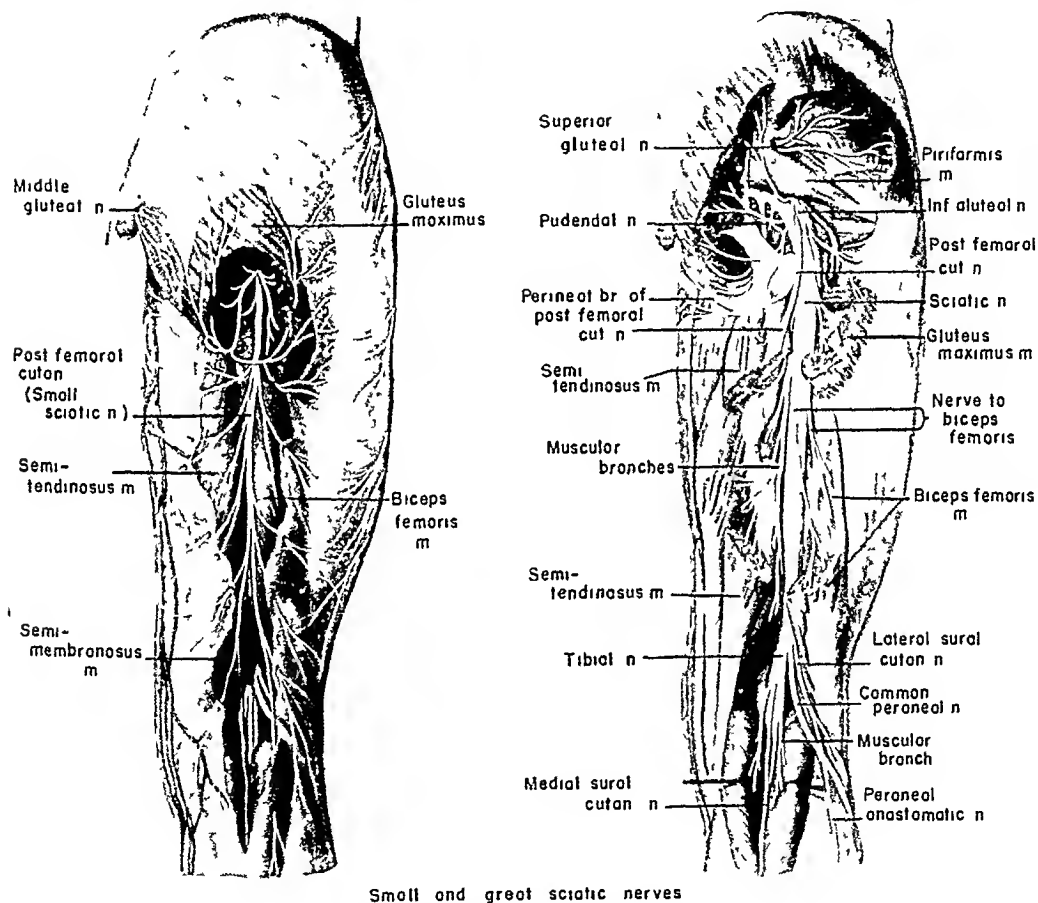


FIG. 260. Small and great sciatic nerves (anatomic). (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux )

foot while injury to the external popliteal (peroneal) produces footdrop from paralysis of the dorsiflexors. The peroneal is frequently injured just above or below the knee joint from fracture, dislocation, and compound wounds It is also not infrequently involved in traction injuries which

the gluteus maximus muscle in operation for high lesions, but when this is done the nerve supply of this muscle should be carefully protected. Partial lesions of the sciatic are by no means uncommon when either the peroneal or tibial may be divided without damage to its companion nerve

The operation for suture of the divided nerve in such cases is not difficult but the two trunks should be separated well above and below the lesion so that there will not be too much angulation in the loop of the uninjured trunk when the ends of its companion nerve are sutured. Marked relaxa-

just at the level where it enters the superficial and deep peronei muscles. It is difficult to trace the peripheral segment of the nerve through the muscles and the situation may be most unfavorable for satisfactory suture. It is here that the desirability of a nerve transplant is often felt,



a                                      b
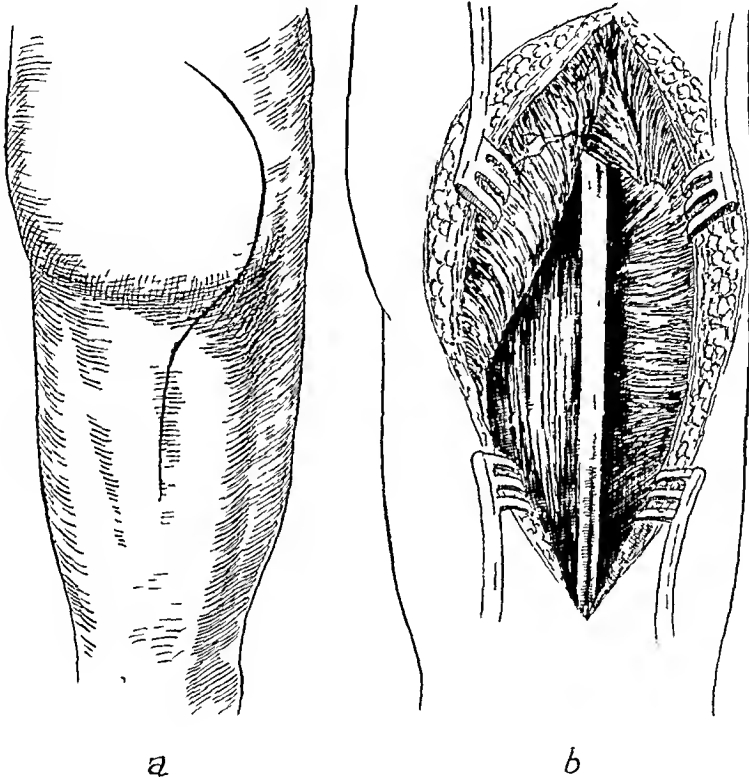
Fig. 261. (a) Incision for exposure of high lesions of sciatic nerve. In lesions above piriformis muscle it may be necessary to divide completely the insertion of the gluteus maximus muscle However, in many cases in lesions slightly lower than this level only lower part of insertion of this muscle is divided.

(b) Exposure of nerve after retraction of gluteus maximus. No important structures are damaged in this incision. Nerve supply to gluteus maximus is not distributed.

tion of the nerve may be obtained by flexion of the leg.

Suture of the nerve trunk is usually easily accomplished, the nerve being a large one. Operation for division of the branches of the external popliteal (peroneal) just below the knee is often most difficult. Division of the nerve often occurs

but this should not be considered unless satisfactory end-to-end approximation is impossible (Fig. 262)

The external popliteal (peroneal) may be compared with the musculospiral (radial) in that its motor supply is given off at a rather high level, whereas the internal popliteal (tibial) supplying the in-

PLATE V
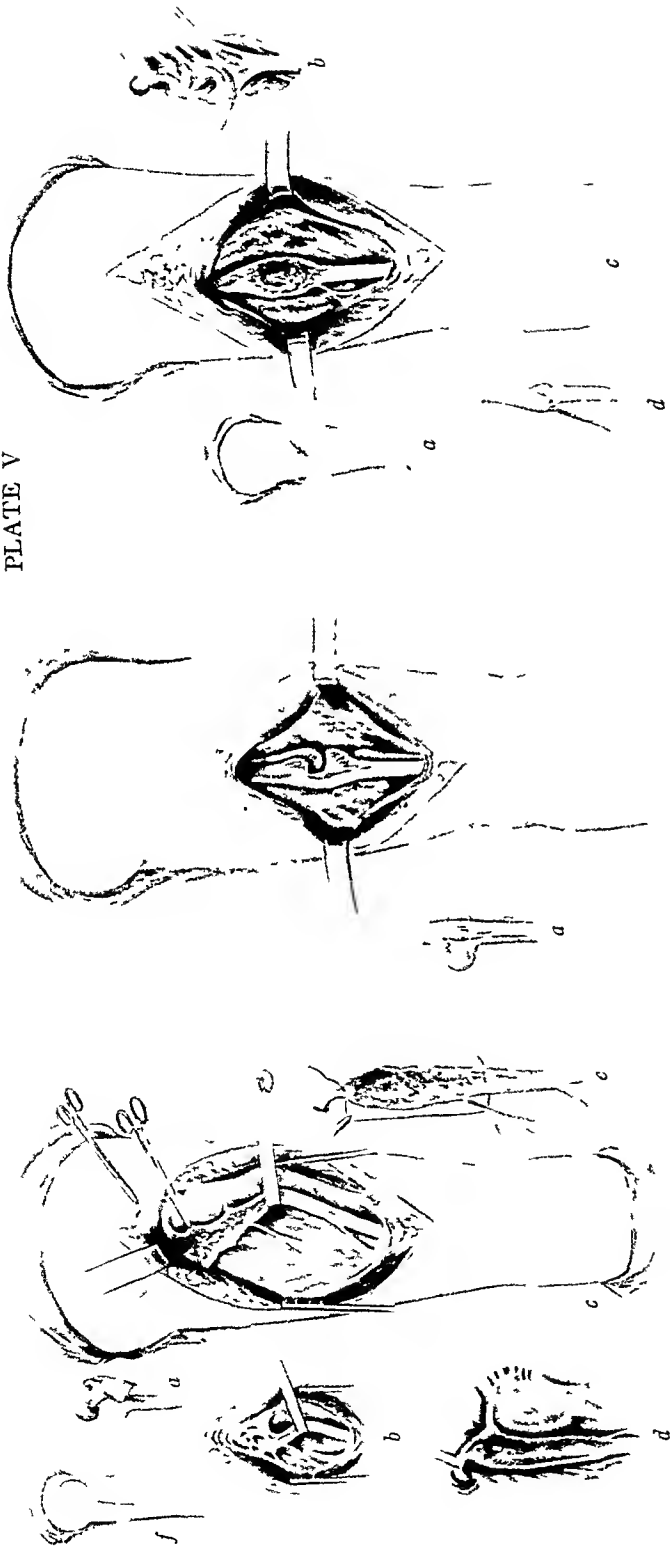


Fig. 262. (*Left*) High gunshot wound of sciatic nerve. (*a*) Fracture of femur caused by missile (*b*) Exposure of nerve below dense scar. (*c*) Further dissection of nerve and exposure of muscular branches. (*d*) Nerve is dissected free from scar tissue. Appearance of a very large dense neuroma in continuity (*e*) A tension suture is placed through healthy nerve about 1 cm from each end of neuroma Neuroma is excised and direct suture made without tension after flexion of leg on thigh This position is maintained for two weeks. (*f*) Line of incision for high lesions of sciatic nerve. In lesions about level of piriformis, tendon of gluteus maximus is divided. This incision allows rapid exposure of nerve and was first used by the writer in 1919.

Fig. 263. (*Center*) Partial division of sciatic nerve in midthigh. Missile completely severed external popliteal constituent of nerve and produced a considerable defect in internal popliteal division. In this case division of sciatic into its two main branches was at a higher level than is usual. (*a*) Neuromas have been removed and direct suture of both external popliteal and severed portion of internal is done. Loop of undivided portion of nerve is shown. In sciatic lesions of this type, preservation of intact portion during suture is more easily accomplished than in any other peripheral nerve.

Fig. 264. (*Right*) Gunshot wound of sciatic nerve. (*a*) Scar of gunshot wound of upper thigh. (*b*) Beginning exposure of nerve, showing it surrounded by dense scar tissue. (*c*) Neuroma of nerve is illustrated. Branch to semitendinosus has been protected during dissection. Excision of dense neuroma left a defect of 3.5 cm. (*d*) Completed suture. Branch to semitendinosus was sutured to inner surface of proximal segment. In this case two tension sutures seemed advisable.

(Courtesy, Surg., Gynec., and Obstet., **78**:113–124 Copyright, 1944, by The Surgical Publishing Co. of Chicago.)

trinsic foot muscles resembles the ulnar and median in that these nerves supply the smaller muscles of the hand and fingers. The internal popliteal (tibial) next to the

nerves and its branches divide into the superficial and deep groups. The superficial group is sensory in type while the deep branches supply the cervical muscles con-
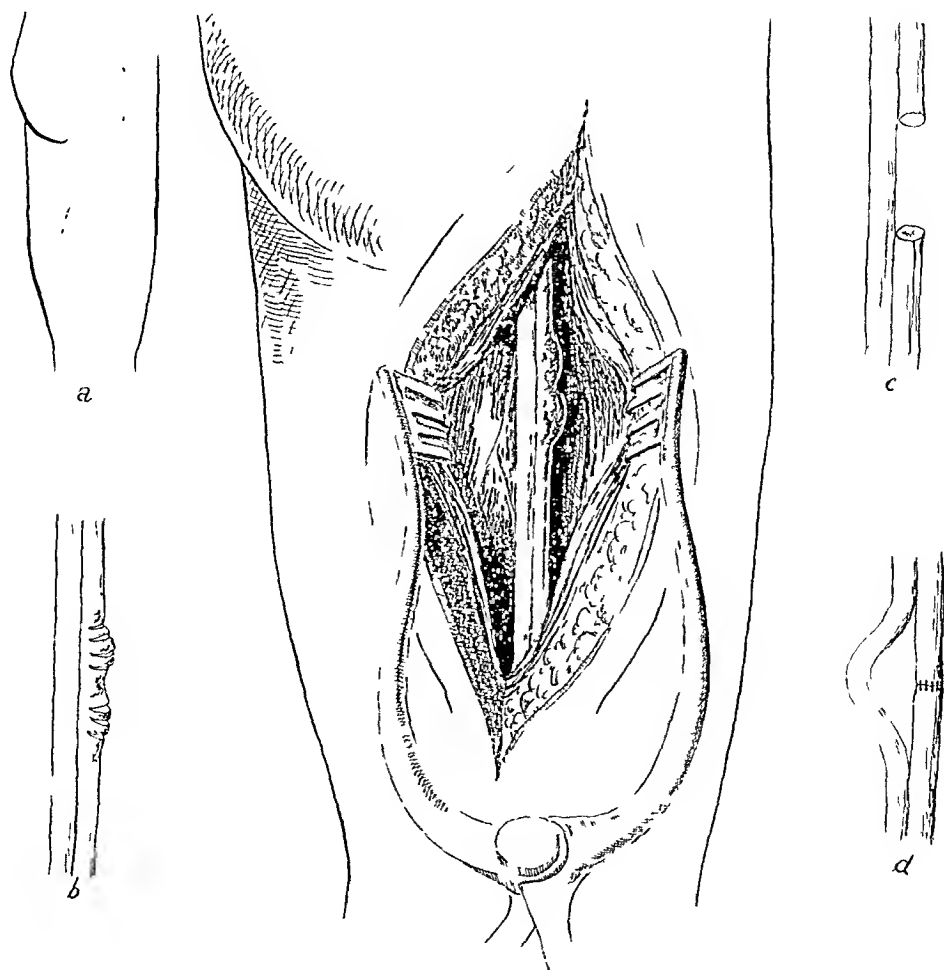


FIG. 265. Complete lesion of peroneal nerve in upper thigh. (*a*) Incision for exposure of lesion. (*b*) Serial section through neuroma to determine extent of necessary excision. (*c*) Gap left after excision of neuroma. (*d*) Approximation of nerve ends with loop of the undamaged portion of nerve. Flexion of thigh permitted approximation of nerve without tension and a penetrating nerve suture was unnecessary.

median is most subject to causalgic disturbance.

## CERVICAL PLEXUS

The cervical plexus is formed by the anterior divisions of the upper four cervical

cerned in rotation of the head and movements of the cervical spine. The phrenic nerve arises principally from the fourth cervical nerve but receives branches from both the third and the fifth nerves.

Operations for traumatic lesions of the

cervical plexus are seldom necessary. Infrequently, a painful neuroma from a partial lesion of one of the sensory branches may require excision. In a few cases of suboccipital neuralgia, which is paroxysmal in

of the second cervical nerve, may be required.

## BRACHIAL PLEXUS

The brachial plexus is formed by the
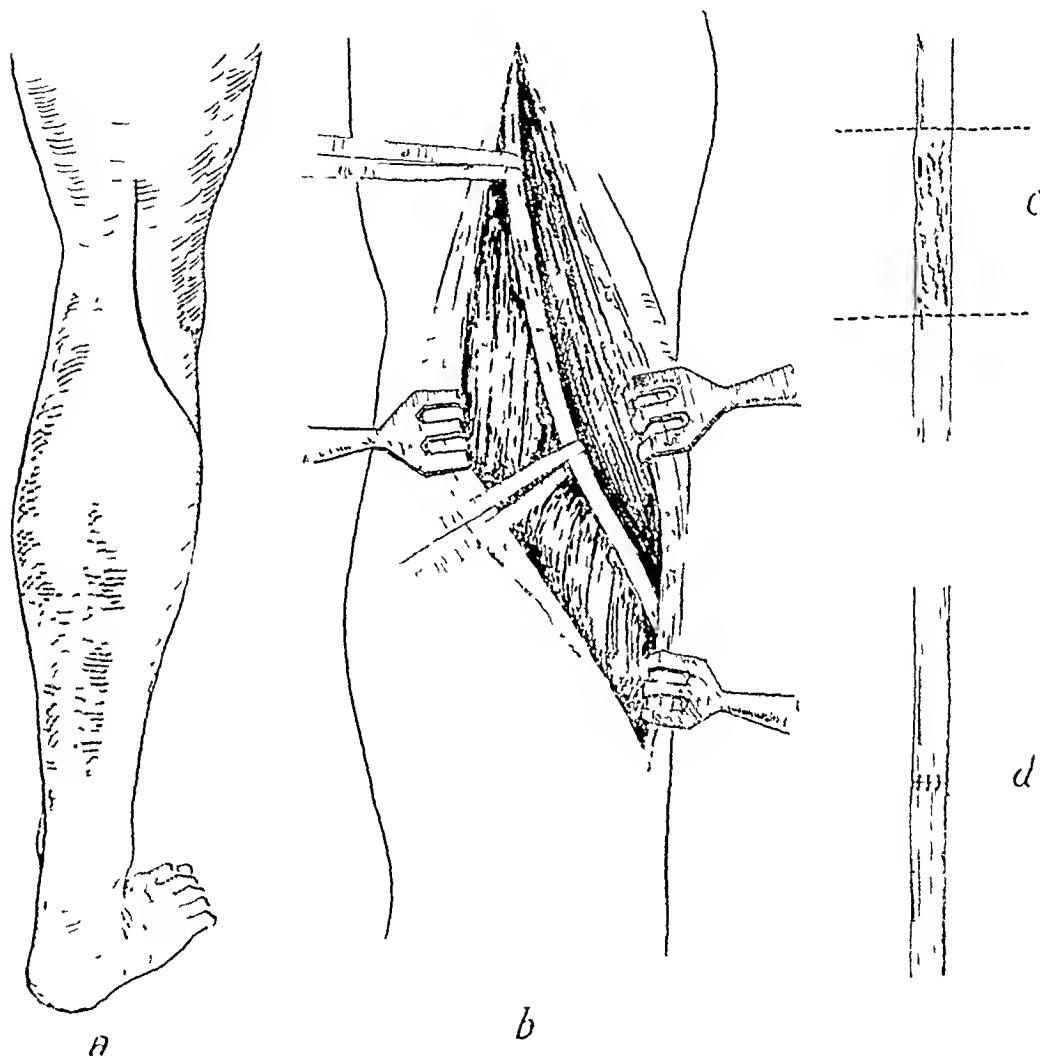


FIG. 266 (a) Incision for exploration of right peroneal nerve at level of knee. (b) Nerve is held with moist tape retractors which facilitate dissection. Scar of a stab wound had resulted in little neuroma formation but practically all fibers had been divided. (c) Extent of resection of injured nerve. (d) Completed suture. No tension suture was used as sufficient relaxation was obtained by flexion of knee, which position was maintained in a plaster cast for three weeks postoperatively.

type, avulsion of the greater occipital nerve, arising from the posterior division

union of the anterior divisions of the lower four cervical nerves with branches from

the fourth cervical and first thoracic entering into its formation. The plexus extends from the lower part of the side of the neck

formed by the eighth cervical and first thoracic nerves. The three cords of the plexus are then formed by branching of

Popliteal vein

Popliteal art

Tibial n

Muscular branches

Common peroneal n

Lat sural cutan n

Common peroneal n

Soleus m

Gastrocnemius m.

Medial sural cut n

Peroneal anostamatic n

Post tibial artery

Tibial n

Medial calcaneal n

Medial plantar n

Lateral plantar n

Common peroneal n

Lat sural cutan n

Articular branch

Tibial n

Popliteal m

Origin of gastroc- nemius

Flexor hallucis longus

Tibial n

Medial plantar n

Lat plantar n

Medial calcaneal n

Tibial nerve

FIG. 267. Tibial nerve (anatomic) (Courtesy, Medical College of Virginia library, after Hirschfeld, Système Nerveux.)

to the axilla. There are variations in the pattern of the plexus but the most common arrangement is the union of the fifth and sixth cervical nerves to form the upper trunk, the seventh cervical nerve forms the median trunk, and the lower trunk is

these trunks. The cords are known as the lateral, median, and posterior cords.

From the lateral cord, the musculocutaneous and outer branches of the median nerve originate. The radial and axillary are the chief nerves of the posterior cord,

while the inner branches of the median, ulnar, the internal cutaneous (medial antibrachial cutaneous) and lesser internal cutaneous (medial brachial cutaneous) arise from the median cord

The plexus may be exposed above the clavicle through an incision about 2 cm.

sion of the incision on to the upper arm so that the lower cords of the plexus may be well exposed The clavicle is wired in position after the necessary procedure on the plexus is completed.

The repair of lesions of the brachial plexus due to gunshot wounds may be very
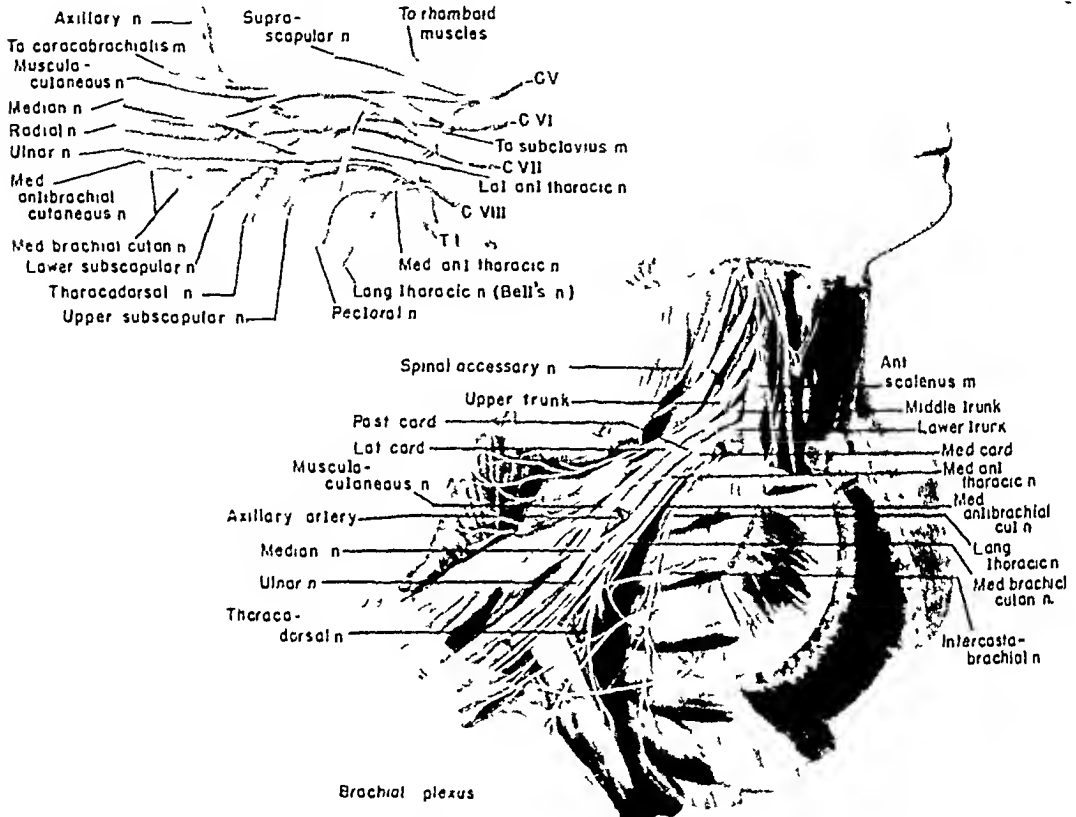


Fig. 268 Brachial plexus (anatomic) (Courtesy, Medical College of Virginia library, after Hirschfeld, Systeme Nerveux.)

above and nearly parallel with the clavicle. The plexus lies posterior to the scalenus anticus tendon, which must be identified for exposure of the plexus. After dissection of the deep fascia the upper cords of the plexus will be seen emerging from behind the scalenus anticus muscle and anterior to the scalenus medius It is intimately associated with the subclavian artery in this region A complete exposure of the plexus requires section of the clavicle and exten-

difficult, not only because of scar tissue involving the neurovascular bundle, but also because resection of the scar tissue from the trunks is quite likely to leave such a defect that direct approximation cannot be accomplished. In such cases transplants have been used but with little chance of satisfactory results

Severe vascular injuries may accompany lesions of the brachial plexus and the resulting ischemia seriously damage the

muscular apparatus of the upper extremity so that functional results following operation are very poor even though a good repair of the trunk or trunks of the plexus has been obtained.

The most common type of brachial-plexus injury in civilian practice is a closed avulsion or severe traction on the plexus from falls involving the shoulder or from birth trauma. Birth trauma may result in severe traction lesions without avulsion of the plexus and such lesions have recoverable tendencies. In severe cases, the lesion may be an avulsion of some or all of the cervical nerves forming the plexus. When the fifth and sixth cervical nerves are avulsed or subjected to severe traction, the patient may have some use of the hand but little of the arm. When the lower cords are avulsed, the nerves supplied by the eighth cervical and first thoracic are paralyzed. An associated finding in involvement of the lower cord is Horner's syndrom. Obviously, surgery is not indicated when there is evidence of complete avulsion of the nerve trunks. Complete avulsion is a rather common result of falls or heavy blows on the shoulder.

### Postoperative Care of Peripheral Nerve Cases

In the large majority of operations for peripheral nerve injuries it is desirable to use some form of dressing or retention apparatus which will support the limb while healing of the sutured nerve is in progress. The position of the limb found most favorable for relaxation of the nerve should be maintained throughout the procedure and for two weeks thereafter. At that time, union of the sutured segments is sufficiently firm to permit gradual restoration of the limb to positions of extension or flexion, whichever may be desired, but this should be carried out very gradually.

The method used in supporting the limb in postoperative care of the patient should not be such as to interfere with circulation. After about two weeks a hinged plaster splint may be applied which will permit gradual extension without allowing sudden severe tension on the sutured nerve.

The splinting of limbs to support the paralyzed muscles is an essential adjunct in the treatment of peripheral nerve injuries. The splints used in musculospiral paralysis may not support the paralyzed common extensors of the fingers, whereas such splints do give support to the extensors of the wrist. It is a matter of common observation that the extensors of the fingers and thumb are much later in recovering function than the extensors of the wrist. It may be that splinting is overdone and further study of the entire subject, particularly as it relates to individual muscles, is highly desirable.

In radial injuries the support of the hand should not extend farther than the end of the proximal phalanges. Such a splint should be so constructed as to permit the patient to reflex the fingers, thus preventing involvement of the joints as far as possible. Moreover, such activity of the extremity as is consistent with the purpose of protecting the sutured segment of nerve is to be desired.

The splinting of paralyzed muscles is done primarily to prevent overstretching of these muscles and not to immobilize the limb. This type of splinting differs from that used in fracture in which complete immobilization is the chief objective. It is highly desirable that the splints used in the care of paralyzed muscle groups be so constructed as to permit action of other normally functioning muscle groups of the extremity.

Light wire splints devised by R. C. Buerki at United States Army Hospital No. 11 at Cape May, New Jersey, in the First World War, still meet all the requirements of splints for wristdrop and footdrop.

## PHYSICAL THERAPY

There is much difference of opinion as to the benefits of physical therapy in the treatment of paralysis resulting from nerve injury. On the whole, the weight of opinion is definitely in favor of such treatment. Physical therapy, particularly massage and passive movements by well-trained technicians, undoubtedly contributes to better end-results. There seems to be some doubt as to the value of electrotherapy and benefits from this have not been so well established as have those of massage and passive movements. The physical therapy should begin as early as possible and continue through the preoperative and postoperative periods until voluntary movement has returned. As soon as the patient begins to show signs of recovering function of the previously paralyzed muscle groups, he should be encouraged to persist in his efforts to use the involved extremity.

When motor paralysis begins to subside after treatment of nerve injury, certain residuals of the paralysis may be diminished by occupational therapy designed to increase the voluntary use of the previously paralyzed muscles. Periarticular fibrosis of the fingers and limitation of motion and contractures in various joints, arising from denervation and disuse, may improve more rapidly under appropriate occupational therapy. The field of occupational therapy is a large one and has shown considerable development.

## CAUSALGIA

The burning pain, usually in the hand or foot, following nerve injury, was described by Weir Mitchell, Morehouse, and Keene in 1864 under the name of "causalgia." Mitchell's description of the condition has been widely quoted in the literature. In recent years, similar painful conditions have been described and attributed to various causes.

The nerves most subject to causalgic pain are the median and tibial, due probably to the more abundant sympathetic nerve supply in these two nerves. Neuritis of the periarterial sympathetics has been offered as an explanation of causalgic pain. In World War I, surgery of the sympathetic nervous system had not been developed. A vast amount of information accumulated on the physiology and surgery of the sympathetic nervous system has furnished a basis for better understanding of causalgia.

The pain of causalgia is described as constant, burning, long-continued, and undermining the morale and general health of the patient. Some patients keep the painful extremity constantly moist and many of them have profuse sweating of the involved extremity. In others the skin is glossy, red, and dry. Patients often protect the painful extremity from any sort of contact and examination for sensory or motor function is difficult. Some patients claim that even noise or excitement intensify the pain. The pain is referred to either the hand or foot, but it is more frequent in nerve lesions of the upper extremity.

Complete division of a nerve is rarely accompanied by causalgic disturbance but such disturbance is not uncommon in incomplete lesions. There are many types of minor pain which probably should not be classified as causalgia, although such cases may present some of the characteristics of this condition. A partial lesion of a small sensory nerve may cause an almost continuous pain, with painful hyperesthesia extending into the distribution of the nerve. The author has observed painful conditions resembling minor causalgia following partial division of the small nerves, such as the median near the wrist or one of the digital nerves. Resection of the lesion and direct suture brought about satisfactory relief of pain.

Patients with causalgia of the ulnar and

median nerves are likely to develop periarticular fibrosis of the fingers, and early operation is indicated. The nerve lesion should be explored, and if it is determined by appearance of the nerve and faradic stimulation that it retains function, a neurolysis should be done, taking great care to remove the nerve from its scar-tissue bed. If the lesion has caused almost complete interruption of the nerve, the neuroma should be resected and end-to-end suture made. However, resection of the nerve does not invariably relieve causalgic pain.

The sympathetic influence on pain in any individual case should be determined. If the hand is constantly moist and cold, the appropriate sympathetic thoracic ganglia (2 and 3) should be injected with 1 per cent novocaine solution. If this relieves the pain it may be repeated with further benefit. The relief of pain in the hand by injection of the sympathetic ganglia is an indication for section of the preganglionic rami to the second and third thoracic ganglia for permanent relief. In causalgia of the lower extremities the indications for injection and resection of appropriate lumbar ganglia are similar to those for the hand.

Mayfield believes that many cases, in which the usual evidence of sympathetic irritation is lacking, may also be benefited by temporary or permanent sympathetic paralysis such as has been found effective in cases showing unmistakable evidence of sympathetic irritation. However, greater care is necessary in selecting these cases in which the extremity is glossy and dry and does not show reduction in temperature.

Alcohol injection of the trunk of the nerve involved, proximal to the lesion, has been used in the treatment of causalgia. Such treatment was not satisfactory in the cases of World War I. The surgical treatment of causalgic pain by operation upon the involved nerve has been uncertain and often disappointing. A better understanding of the sympathetic influence in causalgic pain and the application of appropriate measures to remove this influence may lead to more satisfactory results in the treatment of causalgia. The pain tends to decrease after a number of months but in the meantime the patient may become very much reduced in both general health and morale.

## PAINFUL AMPUTATION STUMP AND PHANTOM LIMB

A high percentage of patients (probably more than 95 per cent) who have had amputation of an extremity are subject to some form of postoperative disturbance of a painful or disagreeable nature in the extremity persisting after the wound has healed. In some of these cases this disturbance extends over many years and may be permanent. No satisfactory explanation has been found for the persisting pain in many of these cases. In the author's experience the most harassing cases of painful stump have been those resulting from amputation for thrombosis of vessels of the extremity. The pain may arise in such cases even before amputation is done and persist for years unchanged. In some few cases the patient may have no postoperative disturbance of consequence for many years. In one case, pain in the amputated stump developed 40 years after amputation.

The presence of pain in amputated stumps has always directed attention to the condition of the nerves at the site of amputation and it is important that the condition of the nerves be carefully investigated. The neuromatous ends may be involved in dense scar tissue which produces considerable irritation of the nerve. If novocaine injection of the neuroma relieves the pain, indications are clear to resect the nerve higher up and to inject alcohol or formalin into the nerve about 3 to 4 cm.

above the level of the new nerve stump. It has been advocated that the end of the nerve be inserted into a canal made in an adjacent bone to prevent neuroma formation. The author has had no experience with this procedure. Cases in which amputated nerves show gross neuroma formation with incarceration in scar may be benefited by further resection of the nerve, but these cases constitute a small percentage of the number who complain of pain in the stump or of referred pain in the hand or foot. The patient often has annoying disturbance from a cramped position of the amputated hand or foot. Disagreeable sensations in the hand or foot may be associated with pain in the amputated stump. It is believed that the painful position assumed in the phantom limb is that position which the patient last recognized prior to amputation.

On the whole, the treatment of painful amputated stump and phantom limb has been very unsatisfactory except for the occasional case when release of the incarcerated nerves and resection of neuromas bring about relief. A satisfactory pathologic explanation has not been found for painful stump and phantom limb. As a result numerous operative procedures have been advocated and most of them with little success. In early or late cases it is best to adopt conservative measures when no local cause can be found for the pain. Among such measures may be mentioned injection of 1 per cent novocaine into the painful area. This may be used freely, as much as 30 cc. or more. Such injection may be repeated from time to time. The fact that some cases have claimed considerable relief from such measure does not necessarily indicate that the case is a psychic one, for there is still much to be learned about pain and its mechanism.

In cases in which the patient is not greatly disturbed, or in early stages of the condition, nothing more than novocaine injection should be tried. It is not advisable to do more than one operation on the nerves of the stump provided the initial exploration investigates all of the nerves which may be implicated in the painful process.

Chordotomy and extensive resection of sensory nerves supplying the painful area have been a complete failure in the author's experience. In one case of painful stump resulting from amputation of the arm just below the shoulder, the sensory branches of cervical 4, 5, 6, 7, and 8 and dorsal 1 and 2 along with the corresponding motor nerves beginning with the fifth cervical were divided intraspinally. Complete anesthesia was produced in the painful area but without the slightest amelioration of pain.

It has been proposed that the sensory portion of the cerebral cortex controlling the painful area and phantom limb be excised. This procedure has been received with considerable interest and although it has had limited use it may provide a sounder and better physiologic approach to the solution of the problem. In one case of intractable pain of a phantom limb Van Wagenen performed a prefrontal lobotomy with gratifying results. Nerve section and section of the spinothalamic tract having failed to relieve the pain, it may be logical to seek an explanation of painful stump and phantom limb at the highest level of the sensory mechanism.

## TUMORS OF PERIPHERAL NERVES

Tumors may develop on any of the peripheral nerves as either single or multiple lesions. They form an interesting pathologic collection but the pathology of these tumors is beyond the scope of the present discussion, the purpose of which is to consider their operative treatment.

The surgical treatment of tumors of peripheral nerves requires in many respects

the same technic used in the repair of peripheral nerve injuries. The removal of any nerve tumor may be very difficult owing to their proximity to important structures, but as a rule the operative procedure is less difficult than that for repair of a gunshot wound of the nerve as scar tissue is absent.

For the purpose of discussing the surgical treatment of peripheral nerve tumors we may consider these lesions in two general classes—the benign and the malignant. Benign tumors of peripheral nerves, as benign tumors elsewhere, are characterized by slow growth and gradual impairment of nerve function. On the other hand, malignant tumors grow rapidly or a tumor formerly showing slow growth may indicate transition to malignancy by taking on sudden rapid growth.

The removal of peripheral nerve tumors requires the same delicacy of technic as is essential to the best results in repair of peripheral nerve injuries. Benign nerve tumors may be removed with little or no damage to the nerve, provided careful technic is employed. Removal of malignant tumors usually requires resection of the nerve with the tumor, followed by direct suture of the nerve, using the same operative technic previously described for the approximation of divided nerves after injury.

Benign tumors, such as neurofibroma, displace the nerve fibers and these fibers may completely surround the tumor. It is a simple matter in these cases to find the line of cleavage between the nerve trunk and the tumor and remove the growth with minimal nerve damage. If the tumor is completely surrounded by nerve fibers, a longitudinal incision should be made over the sheath of the nerve, the fibers gently separated, and the tumor lifted from within its enveloping neural covering. This leaves the nerve collapsed at the site of the tumor but with no appreciable increase of impairment to nerve function. When a benign tumor is removed from within the interior of the nerve the incision of the sheath should be closed with a few fine interrupted arterial silk sutures.

From its rate of growth, the surgeon will have some definite impression as to the histologic character of a tumor prior to operation. Investigation of malignant tumors at operation will show evidence of invasion of the nerve trunk. Conservative operation has no place in the surgical treatment of malignant nerve tumors. The tumor, together with a segment of the nerve trunk well beyond the limits of the growth, should be removed. Immediate repair of the nerve by direct suture should be done, using the same technic for overcoming defects as outlined for peripheral nerve injuries. Approach to the nerve and exposure of the lesion are similar to that used in peripheral nerve injuries.

Conservative operation for malignant tumors will inevitably be followed by recurrence of the growth and the loss of any opportunity the patient may have had for complete cure. The penalty of complete operation for malignant tumors—that is, the production of paralysis—should be fully explained to the patient before operation. It should also be explained that radical operation offers the only chance for permanent eradication of the lesion.

After removal of a tumor requiring resection of the nerve, the same type of postoperative care should be carried out as that following nerve repair in injuries. Proper splinting, adequate and suitable postoperative physical therapy, and appropriate occupational therapy are helpful in the postoperative recovery of nerve function and rehabilitation of the patient. If an accurate approximation of the resected nerve ends is made without tension, the opportunity for the maximum recovery of function is provided.

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# SYMPATHETIC NERVOUS SYSTEM

# 19

# Surgery of Sympathetic Nervous System

## James C. White, M.D.

### INTRODUCTION

Although sympathectomy was first performed in 1889 for epilepsy by Alexander[3] in Liverpool, the first operation undertaken on a sound clinical basis was resection of the cervical sympathetic trunk for angina pectoris by Jonnesco[22] in 1916. In this first successful application the extent of the resection was inadequate according to present standards. The therapeutic value of sympathectomy for Raynaud's disease and Hirschsprung's disease was discovered seven years later as a by-product of Royle[47] and Hunter's[20] unsuccessful attempts to treat spastic paralysis. More efficient methods of sympathetic denervation began about 1925 with Adson and Brown's[2] article on lumbar ganglionectomy for Raynaud's disease and Mandl's[33] discovery in Vienna of the importance of the thoracic cardiac nerves in the transmission of cardiac pain. Diagnostic methods for temporarily interrupting sympathetic impulses with procaine and by physiologic means made their appearance in the early 1930's.[63] With increasing anatomic and physiologic knowledge and the accumulation of critical case reports the early trial-and-error period of sympathectomy has passed.

Operations on the sympathetic nervous system, which are discussed in this chapter, must be anatomically complete and sufficiently extensive so that regeneration cannot take place. If even a few intact axons are left, these are capable of liberating a chemical mediator substance at their endings which can activate the denervated smooth muscle cells and thereby bring about a rapid recurrence of the original disorder.* When only a few centimeters of a sympathetic trunk are removed, as when the second and third thoracic ganglia are resected to eliminate vasoconstriction or sweating in the arm, regenerating axons are likely to bridge the gap in six to nine months. The powers of regeneration are particularly remarkable in the preganglionic neurons. Haimovici and Hodes[13] have presented evidence for regeneration of sympathetic rami even after removal of the entire length of ganglionated sympathetic chain bilaterally, and Simmons and Sheehan[49] and also Smithwick[52] have reported instances of recurrent sweating and vasoconstriction after cervicothoracic ganglionectomy with removal of the inferior cervical and first and second thoracic ganglia. How preganglionic axons can bridge the gap left by removing the cell stations

* For a complete account of the experimental work on regeneration of sympathetic axons and the phenomenon of sensitization the reader is referred to White and Smithwick's monograph on the autonomic nervous system.[63]

of the postganglionic fibers in the paravertebral chains is difficult to comprehend. No satisfactory explanation has been given, but if delicate tests are used to detect recovery (such as rise in cutaneous temperature after blocking the peripheral nerves with procaine and fluctuations in electrical skin resistance) a greater or lesser degree of regeneration can be demonstrated in a surprising number of cases.

No matter what operation is performed, paralysis of smooth muscle is not comparable to that of its striated counterpart. Attention has been called to the clinical importance of sensitization of smooth muscle after denervation to adrenaline and sympathin by Freeman, Smithwick and White,[11] while White, Okelberry and Whitelaw[67] have pointed out the increased effect of this phenomenon when the postganglionic (lower motor) neuron has undergone degeneration. After an injury to one of the large nerve trunks to the extremities the denervated digits may become actually colder than the normal ones whose vasomotor fibers remain intact. This extreme example of a compensatory vasoconstrictor mechanism is due in part, but not wholly, to sensitization to adrenaline and sympathin after postganglionic denervation. Other factors include lowered tissue metabolism and abolition of axon reflexes. Even after preganglionic neurectomy compensatory processes take place within a short period so that some degree of autonomic tone is re-established. Decrease of orthostatic hypotension, which gradually takes place after thoracolumbar sympathectomy and splanchnicectomy for hypertension, is an example of this mechanism. Disappearance of the extreme degree of vasodilation which is present during the first week after sympathectomy for Raynaud's disease is another example, although after an anatomically complete preganglionic sympathectomy a most satisfactory improvement in circulation re-

mains. In spite of these physiologic limitations present-day sympathetic neurosurgery has much to offer in many cases of abnormal vasomotor, sudomotor, and visceromotor activity.

In dicussing the technical procedures of the various operations an effort will be made to review their clinical applications together with the effectiveness and permanence of their results. The anatomic distribution of the more important visceromotor and viscerosensory spinal pathways is illustrated diagrammatically in Fig 269.

The surgical technic of denervation for visceral pain is discussed along with the operative correction of visceromotor dysfunction, although, strictly speaking, visceral sensation is not transmitted over sympathetic axons. To understand this apparent paradox it must be appreciated that the visceral trunks are mixed nerves: the motor axons, which innervate nonstriated muscle and glands, belong to the parasympathetic and sympathetic systems; while the sensory components are a part of the posterior root system of somatic afferent fibers. Provided the anatomic extent of these pain-conducting fibers is known and an adequate surgical or chemical destruction carried out, permanent relief is certain The capacity for regeneration of these sensory fibers is far less than that of the preganglionic visceromotor sympathetic fibers, and after their interruption no compensatory pain-conducting mechanisms come into play to reduce the extent of their paralysis.

## CERVICAL SYMPATHECTOMIES

### RESECTION OF SUPERIOR CERVICAL GANGLION

The superior ganglion of the paired cervical sympathetic chains is a fusiform structure, lying beneath the carotid sheath and extending from the base of the skull 2 to 3 cm. down the neck on the prevertebral

Innervation of Periph. Blood Vessels          Innervation of Viscero — Sensory & Motor
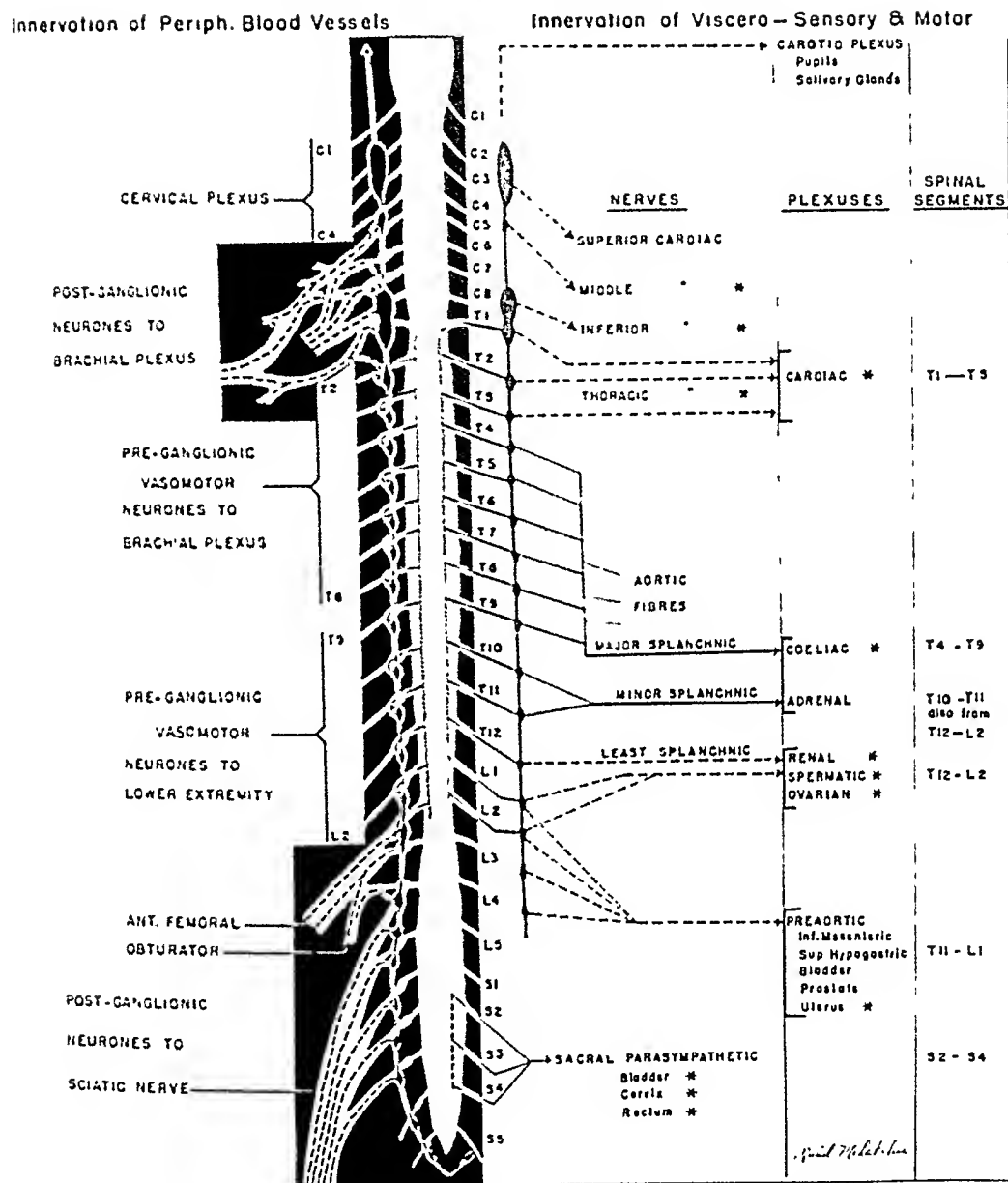


Fig. 269. Outgoing vasomotor and sudomotor fibers to extremities from lateral horn of spinal cord are illustrated diagrammatically on left side. On right side are shown mixed motor (sympathetic) and sensory (posterior spinal root) fibers, together with principal visceral plexuses which they supply and spinal segments from which they are derived.

Preganglionic sympathetic axons are indicated by continuous lines, postganglionic by interrupted lines.

Star (*) indicates presence of pain fibers running to posterior roots.

muscles. It is formed by a fusion of the ganglia connected with the three upper cervical nerves (Fig. 270). In addition to giving off gray rami to these structures, it contributes postganglionic axons to such contiguous structures as the external and internal carotid arteries (and thus to the smooth muscle and sweat glands of the entire head and upper neck), to the carotid

the head rotated away from the side of the incision (Fig. 271, insert). Anesthesia may be induced with ether or by regional infiltration of 1 per cent procaine-adrenaline solution. It is best not to use mixtures of nitrous oxide or cyclopropane with oxygen, because these gases do not reduce the irritability of a sensitive carotid sinus (see p. 490). When local anesthesia is to be used,



Sterno-Mastoid M.

Levator Scapulae M.

Trapezius M.

Subclavian A & V

Scalenus Ant M

Ext Carotid A.

Sup Cerv Ganglion

Sup Cardiac N

Mid Cerv Ganglion & Cardiac N.

Intermediate Ganglion & Annulus of Vieussens

Inf Cerv Ganglion & Cardiac N.

Vert. & Carotid A's

Thoracic Cardiac N's.

Retractor depressing Pleura
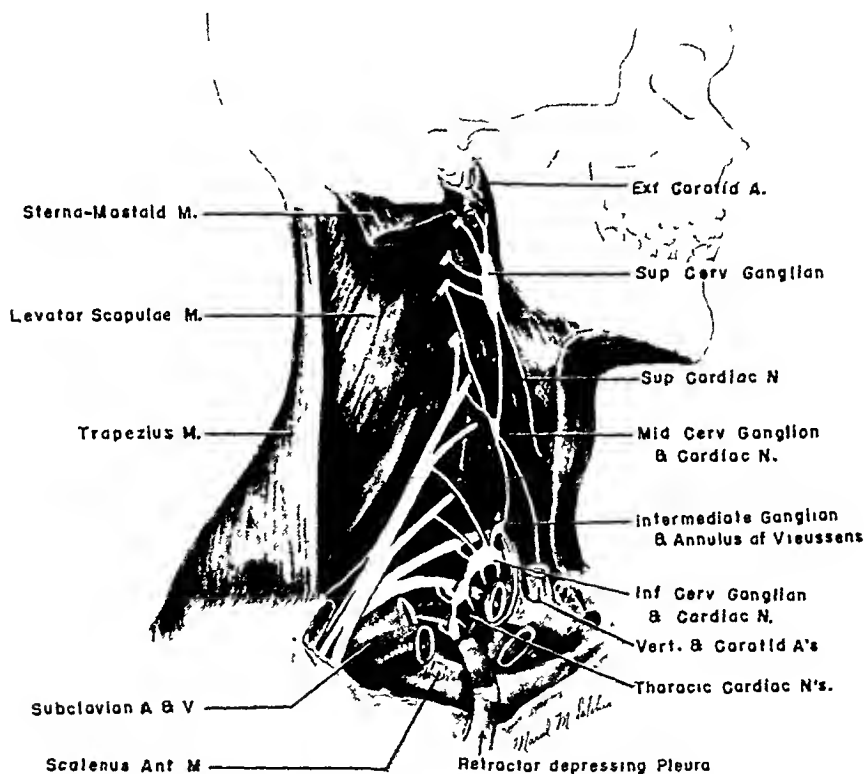
FIG 270 Cervical sympathetic ganglia and their more important rami

sinus, thyroid, lacrimal, and salivary glands, and to the superior pair of cardiac nerves to the heart In so far as is known it transmits only efferent motor impulses and thereby differs from other ganglia of the paravertebral sympathetic chains, which are traversed by sensory fibers from the viscera as well

The surgical resection of this ganglion is carried out with the patient's neck extended over a sandbag or thyroid bar and

one should start with a subfascial injection along the posterior border of the sternocleidomastoid muscle, as this will block the superficial cervical plexus, whose branches become subcutaneous at this point. Further injections around and behind the carotid sheath may be made as necessary in the course of the exposure.

An incision about 7 cm long is made over the posterior edge of the sternomastoid muscle in its upper half, dividing the

fibers of the platysma. It is important to identify the spinal accessory nerve and to spare as many branches as possible of the superficial plexus of the second and third cervical nerves, as shown in Fig. 271. After freeing up the lateral border of the sterno-mastoid and the underlying carotid sheath, these structures should be retracted medially The vagus nerve lies in the under surface of the carotid sheath and usually retracts with it, while the upper portion of

APPLICATIONS

Resection of the superior cervical sympathetic ganglion has few applications. On the basis of anatomic and physiologic investigations, this structure carries no sensory axons and therefore its resection is not a logical procedure to use for the relief of angina pectoris or atypical neuralgias of the head Although in the past there have been a number of reports of its successful
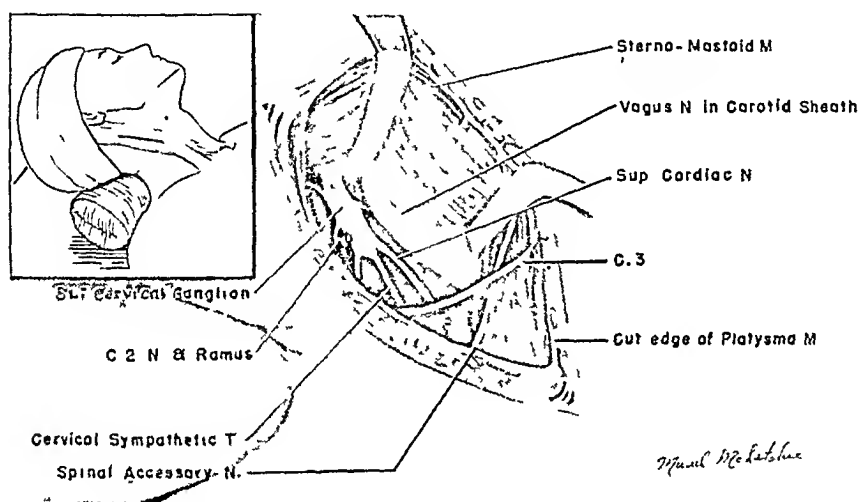


Fig. 271. Superior cervical ganglionectomy.

the cervical sympathetic trunk and its superior ganglion lie in the fascia covering the longus capitis and longus colli muscles.

Once the sympathetic structures have been located, it is an easy matter to divide the trunk below and work upward, cutting the gray rami which connect it with the cervical, glossopharyngeal, spinal accessory, hypoglossal, and vagus nerves The superior cardiac nerve can usually be identified. The ganglion itself reaches nearly to the base of the skull, but if exposure of its upper portion is difficult, resection of its lower two-thirds and a few centimeters of the cervical trunk will suffice to prevent regeneration.

use in these conditions, the operation has failed to give consistent impressive results It is a valuable procedure in severe persistent peripheral facial palsies, where the orbicularis oculi muscle remains paralyzed in spite of suturing the nerve or anastomosing it with the spinal accessory or hypoglossal trunks, so that the patient is unable to close his eye In these cases the partial ptosis which results as part of the Horner's triad enables the sclera to be drawn up and protected beneath the upper eyelid.

A more recent suggestion which should have great practical value has been made by McKenzie of Toronto and Dott of Edinburgh [30] These neurosurgeons have found

that this simple operation has a profound effect in the cases of trophic ulceration which occasionally follows transection of the gasserian root for trigeminal neuralgia. As yet the author has had no personal experience with this use of superior cervical ganglionectomy, but in the face of troublesome corneal ulceration or the rare form of ulceration of the ala nasae it should be given a trial According to Dott, superficial ulcers will heal in three days, and even the late stage of corneal opacity with "partial loss of visual acuity will actually diminish in density and extent with corresponding measurable increase in vision "

### CERVICAL APPROACH FOR RESECTION OF MIDDLE AND INFERIOR CERVICAL SYMPATHETIC GANGLIA, WITH INCLUSION OF THE UPPERMOST THORACIC GANGLIA, IF DESIRED

The stellate is a dumbbell-shaped ganglion 2 5 cm long formed by a partial fusion of the inferior cervical and first thoracic ganglia (Fig 270) It lies against the anterolateral surface of the seventh cervical and first thoracic vertebrae close to the origin of the vertebral artery, and partly above and partly below the head of the first rib It can be easily exposed and resected either by the anterior cervical approach or by the posterior thoracic route The posterior approach is described under Thoracic Sympathectomies (p 465)

When the cervical operation is to be performed, the patient is placed on the table as for a thyroidectomy, but with the head rotated away from the surgeon. Ether-oxygen anesthesia should be administered by an intratracheal tube on account of the risk of perforating the pleura The incision which gives the best exposure is one described by Royle[48] and further improved by Gask.[12] Starting at the tendinous insertion of the sternocleidomastoid muscle, the skin is cut laterally a finger's breadth above the clavicle for a distance of from 5 to 7 cm. (Fig. 272). After severing the fibers of the platysma and dividing the superficial jugular vein between ties, the cervical fat and lymphatics are cleared by blunt dissection to expose the anterior scalene muscle, the cords of the brachial plexus, and the subclavian artery, which emerge from under its lateral border. The thin clavicular head of the sternocleidomastoid is cut to obtain an adequate mesial exposure (and subsequently resutured), also the omohyoid muscle which runs obliquely across the field, but care should be taken to spare as many of the descending branches of the cervical nerves as possible and to retract them out of the way

The next step is to identify the phrenic nerve in the fascia over the scalene and to retract it and the internal jugular vein toward the midline The relation of these structures and the transverse cervical and scapular arteries is shown in Fig. 272. The anterior scalene muscle is now cut across just above its insertion in the first rib. Cutting across the sternal head of the sternomastoid and anterior scalene muscles is the key to a wide exposure of the vertebral artery, the stellate, and the ganglia just below it When the scalene fibers have been allowed to retract, the underlying subclavian artery can be followed centrally into the thorax. After ligating and cutting the thyroid axis, one should develop the lower end of the common carotid, which arises as a branch of the subclavian on the right and has a separate origin from the aorta on the left Once the lower portions of the subclavian and the common carotid arteries have been cleared, the vertebral comes into view as a posterior branch of the subclavian The stellate ganglion can now be visualized with its delicate rami, lying just medial to the origin of the vertebral artery and against the bodies of the seventh cervical and first thoracic vertebrae (Fig. 273).

In this part of the operation it must be borne in mind that important anatomic structures lie at the edges of the field, but are often hidden from view. The subclavian vein lies just anterior to the artery, the dome of the pleura just beneath it. In operating on the left side, one should try to expose the thoracic duct and protect it with a cottonoid strip. It can usually be seen as it emerges from the depths of the mediastinum from behind the jugular vein and enters the subclavian at their point of confluence. Clearing the subclavian artery down into the mediastinum· requires a bloodless field and the best possible illumination from a lighted retractor or a headlight. The structures are cleared by blunt dissection, spreading with the tip of a pair of curved scissors, and wiping with a cotton pledget grasped is an angulated Hartmann forceps.

If, in addition to the stellate, the upper thoracic ganglia are to be included in the resection, the next step is to cut Sibson's fascia, which attaches the apex of the pleura to the posterior portion of the first rib. Once this suspensory ligament has been cut it is possible to separate the dome of the pleura from the posterior central portion of the ribs and the bodies of the upper three thoracic vertebrae. The actual resection of the trunk is best begun by elevating the inferior cervical ganglion on a nerve hook and making traction to expose the many connecting rami which give rise to its name. When the fibers which run to the cords of the brachial plexus have been cut, the ganglion is grasped in a hemostat. One should proceed next by cutting the large rami which join the first thoracic ganglion to its spinal nerve, and then the more delicate central connections of the two lower ganglia with the second and third intercostal nerves. This is usually the lowest point to which a dissection from above can reach. On account of the hazard of cutting a small blood vessel instead of

a nerve deep in the chest, it is safest to apply dural clips to each structure before it is severed.

The extent and type of resection of the ganglionated chain will depend on the purpose for which the operation is undertaken For the reduction of vasoconstriction in Raynaud's disease, the inferior cervical and upper two thoracic ganglia should be preserved, but their connections with the trunk below and with the second and third spinal nerves divided. This operation, described by Telford,[58] constitutes a preganglionic denervation of the vascular tree to the arm and head and renders the vessel walls less sensitive to circulating adrenine and sympathin than if the ganglia, which contains the postganglionic neuron cells, are destroyed. After the chain has been cut below the third thoracic ganglion and the rami which join the second and third thoracic ganglia to the intercostal nerves have been severed, all spinal vasoconstrictor and sudomotor fibers to the arm and head are interrupted (none leave the spinal cord over the first thoracic or higher segments). The oculopupillary fibers in the first thoracic ramus are preserved and the patient is therefore spared a disfiguring Horner's syndrome.

In order to minimize the likelihood of regeneration, the freed-up cephalic end of the chain should be swung up and buried in the neck as far as possible from its caudal end. On the other hand, for the relief of cardiac pain it is of vital importance that the upper three thoracic ganglia be resected over their entire length. Failure to remove the entire third ganglion in one of the author's patients with angina pectoris resulted in continued attacks of low precordial pain, which disappeared after subsequent resection of the remainder of this ganglion, together with the fourth, through a posterior approach.

After completion of the resection or decentralization of the ganglia, and when all

bleeding points have been controlled, the incision is closed in layers without drainage. The clavicular head of the sternocleidomastoid is resutured, but this is neither necessary nor feasible with the retracted ends of the omohyoid and anterior scalene muscles The finest possible silk should be used for ligatures and sutures throughout

figurement of a Horner's syndrome. For cosmetic reasons it is therefore preferable to employ the preganglionic type of denervation.

After this operation recurrence of sweating has never been extensive, although vasoconstrictor activity may recur to a troublesome degree. This partial recovery of vascular tone can take place because the
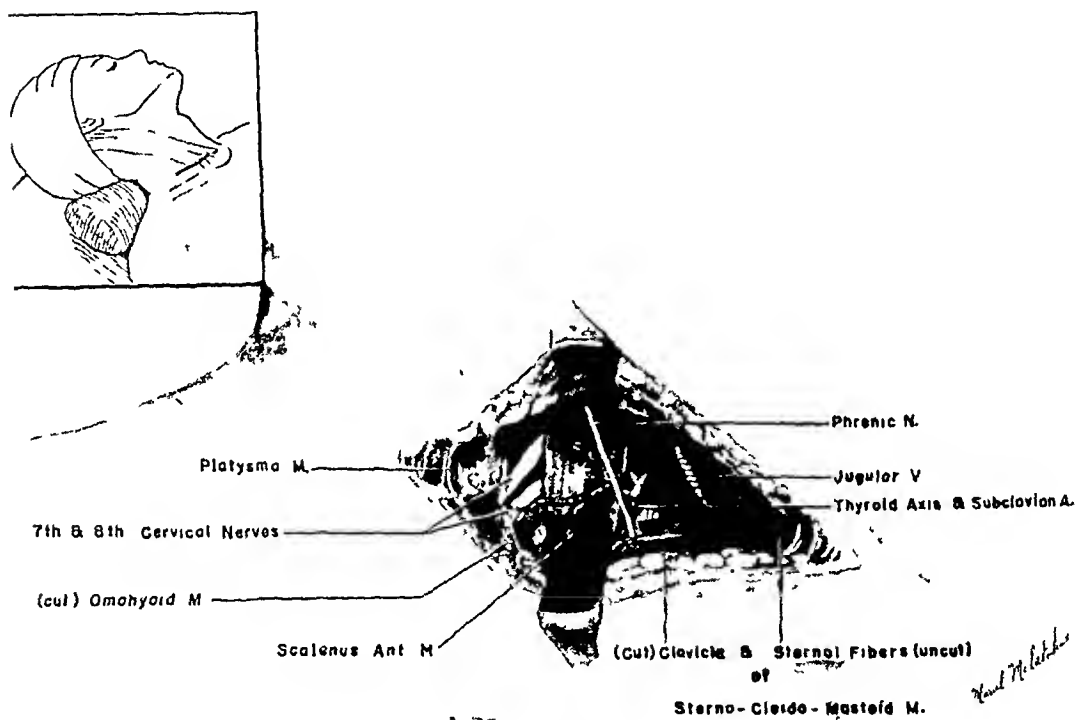


FIG. 272　Cervicothoracic ganglionectomy by cervical approach:
Exposure of anterior scalene muscle, phrenic nerve, and blood vessels at base of neck. Clavicular fibers of sternocleidomastoid muscle and omohyoid muscle have been divided.

APPLICATIONS

Cervicothoracic ganglionectomy (postganglionic denervation of the upper extremity) is a satisfactory method for abolishing the secretion of sweat in cases of severe palmar hyperhidrosis, because the denervated sweat glands are not activated by circulating adrenine or sympathin This operation, however, entails the slight dis-

cervical route does not enable the surgeon to excise the anterior roots of the second and third cervical nerves well back inside the meninges, where the dura will form a barrier against their regeneration. The cervical approach is therefore inferior to the posterior route for the treatment of Raynaud's disease and other allied conditions. For similar reasons the posterior approach should be more lastingly effective in cases

of causalgia, traumatic arthritis, and amputation stump pain, which are often associated with chronic vasospasm and are frequently relieved by any method which restores an active circulation. The author has observed a recurrence of pain in a patient with the latter condition after relief for six months following an incomplete sympathectomy; the recurrence was synchronous with the return of neurogenic vasoconstriction.

of the corresponding vertebrae. The large dumbbell-shaped stellate ganglia are situated near the ventral edge of the bodies of the last cervical and first thoracic vertebrae, the inferior cervical component above and the first thoracic component below the heads of the first ribs. The chains then gradually assume a more dorsal position, looping over the central articulations of the ribs and finally passing beneath the medial arcades of the diaphragm. The
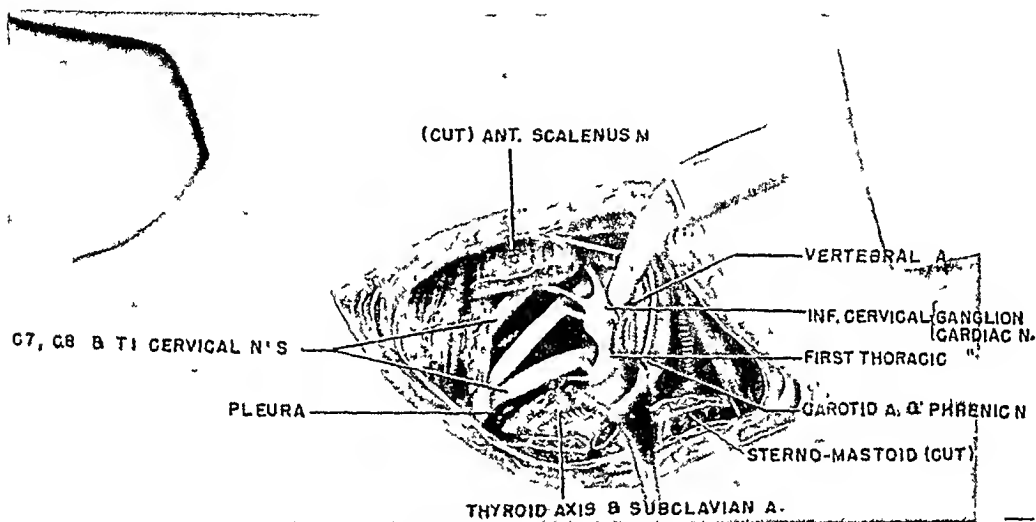


FIG. 273. Cervicothoracic ganglionectomy by cervical approach:
Subclavian artery and dome of pleura are shown retracted downward after anterior scalene muscle, thyroid axis, and Sibson's fascia (apicopleural ligament) have been cut. This permits a wide exposure of first portion of subclavian artery, its vertebral branch, and cervicothoracic (stellate) ganglion.

For the relief of angina pectoris, resection of the upper three thoracic ganglia by the anterior approach can be carried out most satisfactorily in a thin-necked patient, but given an obese short-necked individual a more adequate exposure can be obtained by the posterior incision through the second rib.

## THORACIC SYMPATHECTOMY BY POSTERIOR APPROACH

The thoracic sympathetic ganglia lie in the retropleural areolar tissue on the sides

twelfth thoracic ganglia lie buried in this muscle. Each thoracic ganglion is united to its corresponding spinal nerve by a pair of rami communicantes. The white rami carry efferent sympathetic fibers destined for smooth muscle and glands, and also afferent fibers from the internal organs. The latter are not sympathetic fibers, but belong to the posterior root system. They play an important rôle in regulating visceral reflexes and, under certain circumstances, transmit pain to the sensorium. The gray rami carry the sympathetic post-

ganglionic fibers to the peripheral nerves and also motor and sensory fibers to the visceral plexuses. The most important of these make up the thoracic cardiac nerves ($T_1$-$T_4$) and major ($T_4$-$T_9$) and minor ($T_{10}$-$T_{11}$) splanchnic trunks. These connections are shown in Fig. 269.

While the sympathetic chain can be exposed as far down as its third thoracic ganglion through the anterior approach in the base of the neck, the surgeon cannot obtain as close and unobstructed an exposure as when these structures are approached through the back. The idea of removing the posterior segment of the first or second rib to gain a better exposure of the sympathetic trunk was evolved by Adson.[1] In operations for Raynaud's disease prior to this, only the inferior cervical and first thoracic (stellate) ganglia had been resected in a more limited cervical operation than the one described above. The resultant interruption of sudomotor and vasoconstrictor fibers to the arm was often incomplete, due to the fact, pointed out by Kuntz,[23] that the second and sometimes the third thoracic ganglia may give off gray rami to the brachial plexus. Adson's posterior paravertebral incision permitted a wide resection of the inferior cervical and upper three thoracic ganglia: This is a most effective method for denervating the heart and the sweat glands of the face and upper extremity. Unfortunately its effectiveness in producing satisfactory vasodilatation of the arm and hand is vitiated by the fact that it causes degeneration of the postganglionic vasoconstrictor fibers to the vascular tree of the upper extremity, as their trophic cells lie in these ganglia (Fig. 269). An operation of this sort renders the sensitized vessels extremely reactive to circulating adrenaline and sympathin.[48] The experience of the Peripheral Vascular Clinic at the Massachusetts General Hospital showed that vascular spasm in the denervated arm still persisted to such a degree

that neither the staff nor the majority of the patients felt that the improvement in circulation was sufficient to justify the procedure.

On the other hand, resection of the second and third lumbar sympathetic ganglia resulted in lasting and most satisfactory vasodilatation of the lower extremity. As the cells of the postganglionic vasoconstrictor fibers to the lower leg and foot lie in the lowest lumbar and sacral ganglia (Fig. 269), only preganglionic fibers are sectioned in the standard lumbar sympathectomy. As a result the vascular tree of the leg becomes only slightly sensitized to circulating sympathomimetic hormones, and blood flow through the feet remains permanently increased. After cervicothoracic ganglionectomy, however, where the postganglionic outflow of vasoconstrictor fibers to the brachial plexus is destroyed, the maximally sensitized blood vessels of the arm and hand still constrict to a significant degree in the presence of circulating adrenaline or sympathin. This clinical application of a fundamental physiologic principle was first pointed out by White, Okelberry and Whitelaw.[67]

Utilizing this principle, Smithwick in 1936[50] proposed a modified form of upper thoracic sympathectomy, in which the ganglia containing the postganglionic neuron cells to the upper extremity are preserved, but the preganglionic fibers which carry vasoconstrictor impulses from the spinal cord to these more peripheral stations are cut. Recognition of the fundamental physiologic principle of sensitization and the substitution of preganglionic for the old postganglionic denervation of the brachial plexus have produced a great improvement in the surgical treatment of Raynaud's disease in the upper extremity. Even with this technical improvement in the type of sympathectomy, however, it cannot be claimed that the results are as good in the hands as in the feet. Severed

preganglionic axons have an extraordinary capacity for regeneration, so that significant degrees of relapse have necessitated minor changes to overcome this difficulty. In addition, local changes in the arteries of the hands of the patient with Raynaud's disease appear to be more pronounced than in the feet, so that the disease in the upper extremity is actually more resistant to treatment.

Regardless of whether it is desired to resect the upper thoracic sympathetic ganglia
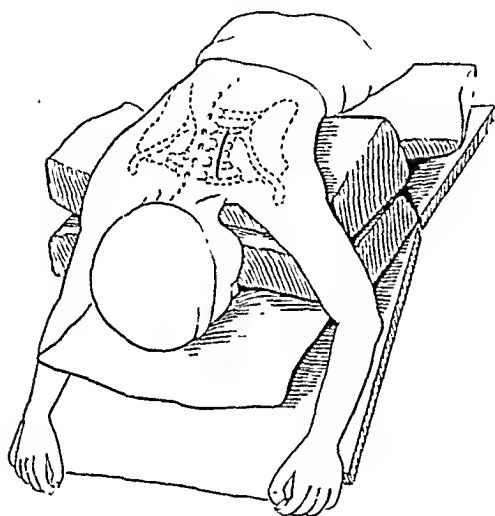


Fig. 274. Upper thoracic sympathectomy by posterior approach:
Position of patient and line of incision. Note position of pillows to permit free abdominal respiratory movements and anterior flexion of neck.

or, in special conditions such as Raynaud's disease, while preserving the postganglionic network of vasoconstrictor neurons, to sever their central connections, the exposure of the sympathetic ganglionated chain is the same. Ether anesthesia should be administered by the intratracheal route, as opening the pleura is a complication which cannot always be avoided. The patient is placed on the operating table face down, with several pillows under the chest so that

the shoulders slope slightly forward and wrinkles in the neck are smoothed out (Fig. 274). Care should be taken that the abdomen is not compressed but free to expand with the respiratory movements of the diaphragm.

The incision is made 5 cm. lateral and parallel to the spinous processes, 7 to 10 cm. in length, and centered over the rib to be resected. In case it is planned to remove the upper three thoracic ganglia, the incision should be centered over the second rib, but for a preganglionic sympathectomy the surgeon should choose the third. The fibers of the trapezius, major and minor rhomboid, and serratus posterior superior muscles are cut across* to expose the central ends of the upper ribs and the erector spinae muscle. It is necessary to mobilize the lateral border of this muscle and retract it with the overlying muscles with a self-retaining retractor. This should expose some 3 to 4 cm. of the rib to be resected together with its transverse process (Fig. 275).

The next step is to free the rib from the intercostal muscles and underlying pleura with a periosteal stripper and cut it off 4 cm. lateral to its articulation. The pleura is then freed toward the midline with a finger and dry gauze, rongeuring away most of the central end of the rib and its transverse process. It is important to remove these structures just as far centrally as possible, as this serves to unroof the region where the ganglia lie (Fig. 276). Also, one must be careful to bevel off the rongeured ends of bone smoothly so that no sharp points are left to puncture the pleura.

Once the rib has been resected, it is an easy matter to strip the pleura. It should

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* When the approach is made through the second rib, it is also possible to make an oblique incision, which permits separation of the muscle fibers in the plane of the fibers. This incision was devised by White, Smithwick, Allen and Mixter.[69] It does not give adequate exposure for resection of the third rib.

be freed widely from the sides of the contiguous thoracic vertebrae and the under surfaces of the rib above and below. The best instrument for this purpose is the tip of the index finger, assisted at times by a wet cotton paddy grasped in a Hartmann forceps.

monly used in exposing the trigeminal root. With a good light and adequate depression and lateral retraction of the pleura one obtains a clear view of the sympathetic ganglia, the rami connecting them with the intercostal nerves, and also of the fibers run-
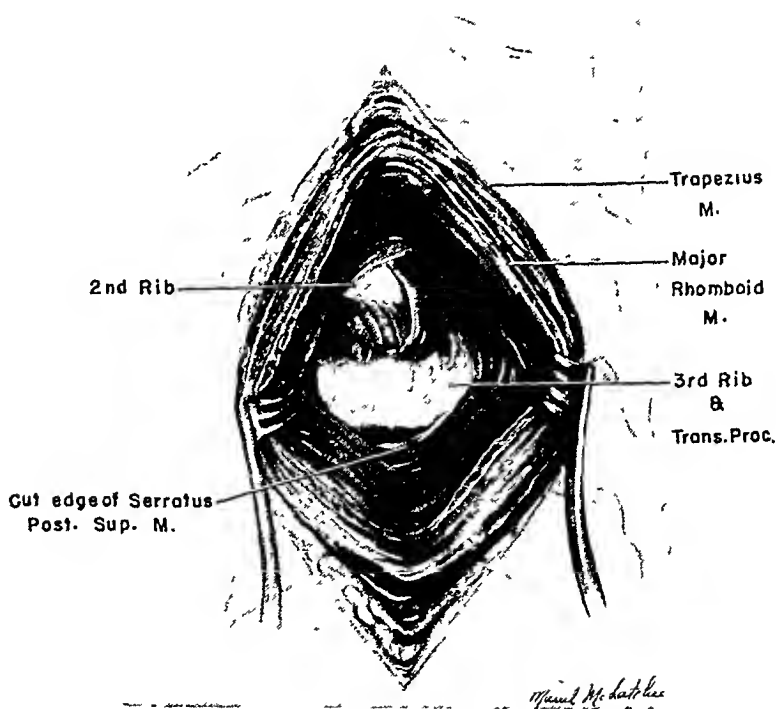


FIG. 275. Upper thoracic sympathectomy by posterior approach: Back muscles have been cut and retracted to expose central portion of rib and transverse process which are to be resected.

In this and the following illustrations, structures are illustrated from angle seen by surgeon, who is working from left side of table and facing toward patient's head.

ceps. The sympathetic chain comes into view by the time the pleura has been freed nearly to the anterior edge of the vertebrae. The pleura should now be protected with cottonoid strips and retracted with a lighted ribbon retractor of the type com-

ning ventrally to the pulmonary and cardiac plexuses (Fig. 277).

In order to perform a cervicothoracic ganglionectomy the approach should be made through the second rib and the apical pleura thoroughly freed from the sides of

the upper three thoracic vertebrae. It is then an easy matter to identify the large dumbbell-shaped stellate ganglion and the numerous rami which run upward to the cords of the brachial plexus, particularly from its inferior cervical component. This ganglion lies slightly rostral to the head of the first rib, whereas the first thoracic is situated at its lower border and has an un-

tion of the brachial plexus is somewhat more complicated than simple resection of the chain The upper thoracic and inferior cervical ganglia, which contain the postganglionic neuron cells, must be carefully protected while all their central connections are cut The anatomic details necessary for an understanding of this operation are shown in Fig 269 In brief, a complete in-
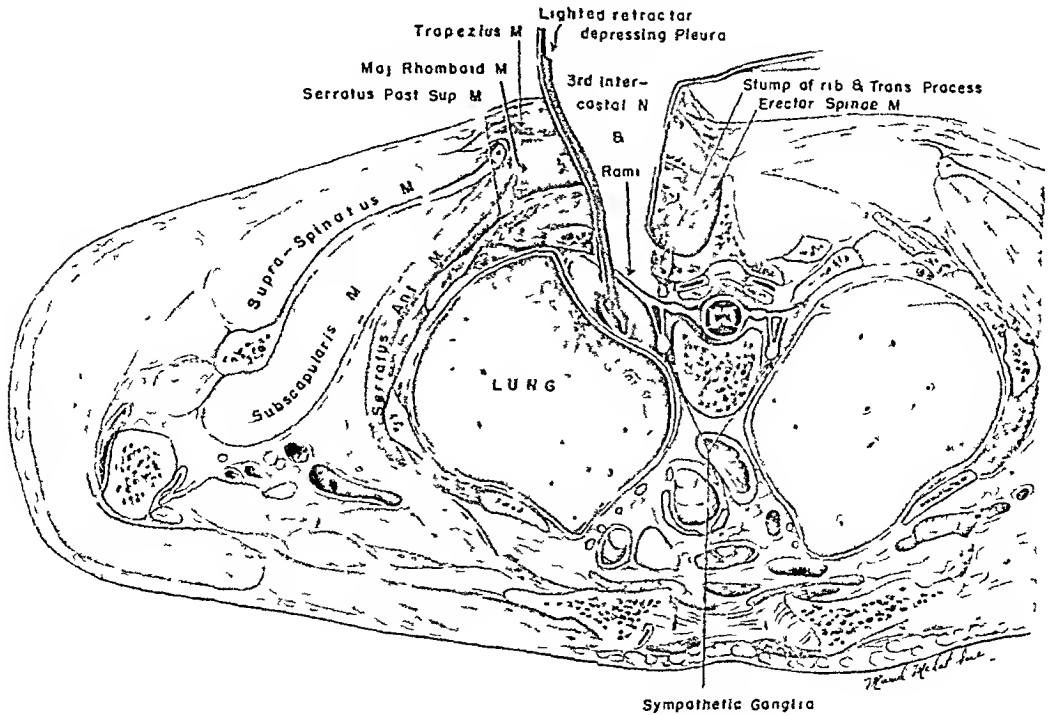


FIG 276 Upper thoracic sympathectomy by posterior approach:
Transverse section of body to show exposure of ganglionated chain after excision of rib and transverse process. Pleura is depressed with an electrically lighted ribbon retractor.
(Modified from Eycleshymer and Schoemaker: A Cross-Section Anatomy, New York, D Appleton-Century Co )

usually thick ramus uniting it with the large first thoracic nerve (Fig. 270). It is usually best to divide the trunk below its third thoracic ganglion first and then to work upward, freeing it from the sides of the vertebrae as its rami are successively cut.

The procedure for preganglionic denerva-

terruption of the preganglionic vasoconstrictor fibers can be accomplished by cutting the chain below its third thoracic ganglion, which eliminates all the lower fibers coming from the anterior thoracic roots as far down as the eighth, and then interrupting the remaining spinal connections with the second and third thoracic seg-

ments Fortunately no vasoconstrictor fibers emerge over the first thoracic root, so that this important structure can be preserved and a Horner's syndrome avoided.

The exposure of the ganglia in this op-

The next step is the most difficult part of the procedure to perform in such a way that the sympathetic motor fibers will not promptly regenerate. Regeneration will occur within a few months if only the rami
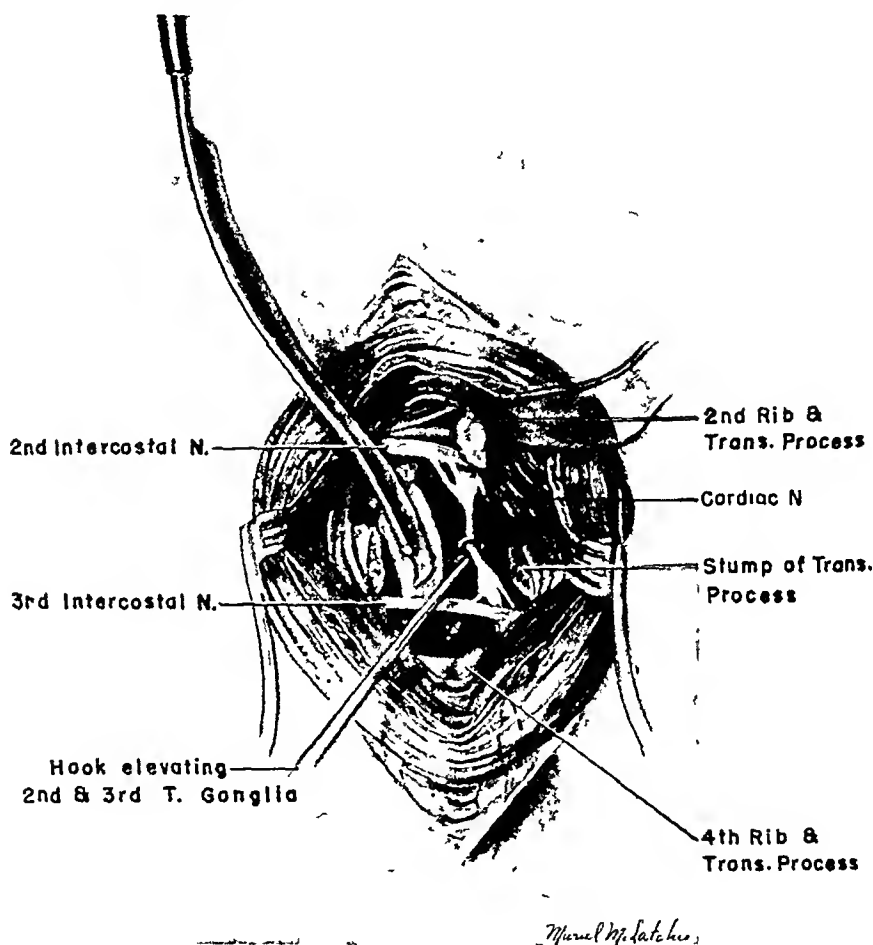


FIG. 277. Upper thoracic sympathectomy by posterior approach:
Surgeon's view of structures shown in Fig. 276. When upper three thoracic ganglia are to be excised for relief of angina pectoris, approach should be made through second rib. To perform the older type of postganglionic denervation of the brachial plexus it is best to center incision even higher and excise a portion of first rib in order to obtain best exposure of inferior cervical and upper two thoracic ganglia with their rami to brachial plexus.

eration is obtained through the third rib, in order to give a clear view of the second and third ganglia and the two corresponding intercostal nerves. It is a simple matter to cut the chain below its third ganglion.

connecting the ganglia and intercostal nerves are cut. It will occur with almost equal facility if the intercostal nerves are cut off just central to the point at which these rami are given off.

The only effective way to prevent re-growth is to make traction on the inter-costal nerve until the sensory ganglion on the posterior root is drawn out of the in-
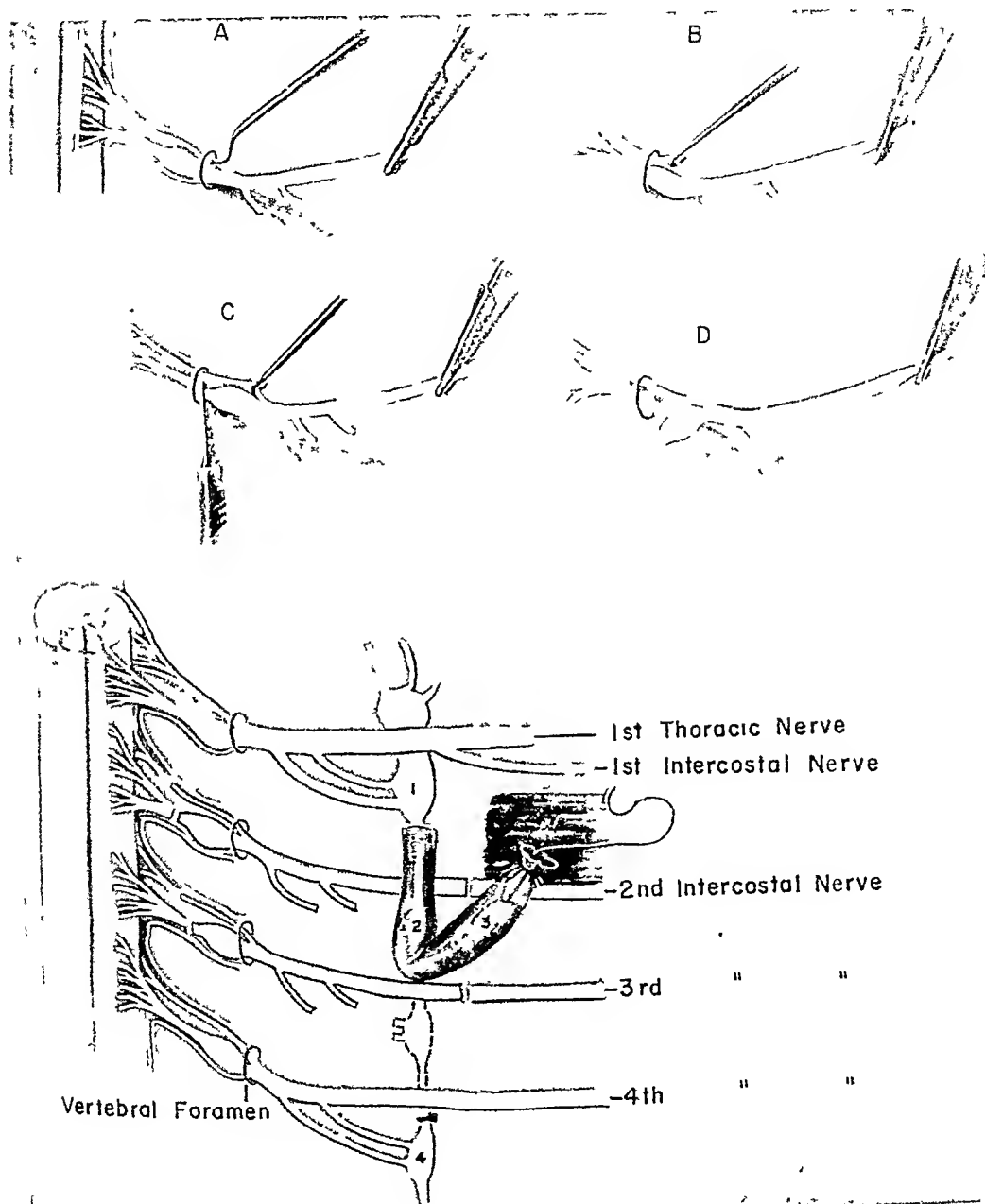


FIG 278 Upper thoracic sympathectomy by posterior approach·
Preganglionic denervation: Technic of intrathecal rhizotomy of second and third intercostal nerves and method of dealing with decentralized ganglia to prevent regeneration of central connections (Smithwick[3]). See description in text.

tervertebral foramen. This is not difficult to accomplish if the head of the rib and transverse process have been rongeured back to the side of the vertebrae, so that the foramen is clearly exposed (Fig. 276). Dissection with a dental spatula around its periphery (Fig 278 A) as traction is made on the nerve suffices to bring the swelling

motor fibers, before it breaks off (Fig 278 D)

Usually a few drops of spinal fluid run out at this stage. This means that the root has been divided intrathecally and that the closure of both the arachnoid and the dura will effectively block off the egress of regenerating preganglionic axons. Both the
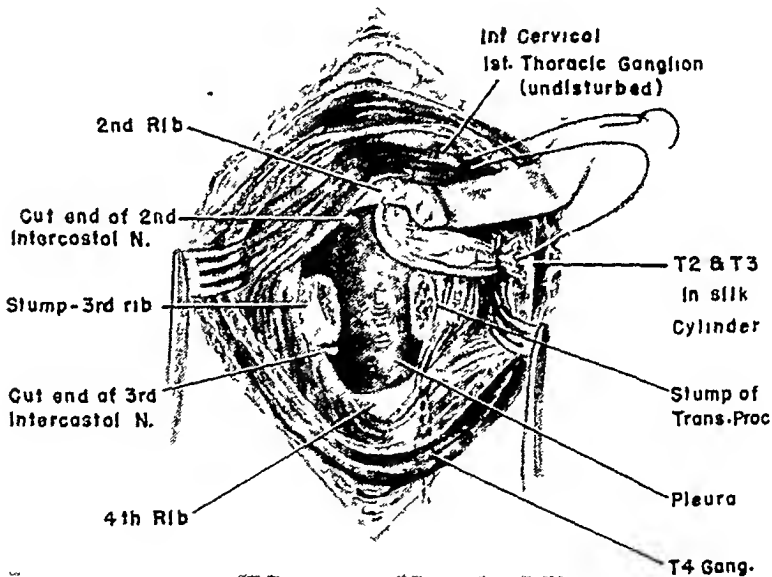


FIG. 279. Upper thoracic sympathectomy by posterior approach
Final step in Smithwick type of preganglionic sympathectomy·
Decentralized second and third thoracic ganglia have been encased in a silk cylinder, whose free lower end is being swung up and anchored in posterior muscles

of the sensory root ganglion into view A hook is then inserted between the anterior and posterior roots (Fig 278 B) and further traction made until the posterior root can be cut off central to its ganglion Further gentle traction is then sufficient to draw out a full centimeter of the anterior root, which contains the sympathetic

third and the second spinal nerves are dealt with in this fashion, excising both the roots and from 2 to 3 cm of the nerve trunks.

Once the central connections of these ganglia have been cut inside the meninges, all that remains is to prevent regenerating fibers from bridging the gap between the

two ends of the sympathetic trunk. The most effective means of accomplishing this end has been described by Smithwick.[53] It consists of slipping a sleeve of fine silk over the free cephalic end of the sympathetic trunk. This is slid over the second and third thoracic ganglia up to the intact rami of the first (Fig. 279). Its open lower end is tied and then secured in the intercostal muscle as far away from the central stump as possible. The purpose of this maneuver is to prevent regrowth of fibers between the severed ends of the sympathetic trunk or with the stumps of the second and third intercostal nerves, provided the latter have not been amputated within the meninges. No one who has not had long and extensive experience with sympathectomies can realize the ability of the preganglionic fibers to regenerate.

Regardless of which of the two varieties of sympathectomy described above has been performed, closure of the incision is the same. If the pleura has been perforated, the anesthetist should inflate the lungs to drive out all the air which has entered the pleural cavity. The muscles, fascia, and skin are closed in layers with interrupted sutures of fine silk. No drainage is necessary.

### APPLICATIONS

In all operations for the increase of circulation through the upper extremity it is best to use the preganglionic type of sympathectomy. The physiologic reasons for this have been discussed briefly above and at length in White and Smithwick's monograph.[68] In cases of hyperhidrosis, where denervation of the sweat glands is the sole end in view, ganglionectomy is equally effective, as the paralyzed sweat glands are not activated by either adrenaline or sympathin. However, it is always desirable to avoid a Horner's syndrome, and for this reason it is best to leave the inferior cervical and first thoracic ganglia intact.

Sympathectomy is frequently a most valuable means of dealing with painful posttraumatic arthritis (Sudeck's atrophy), pain in an amputated stump, the phenomenon of the phantom limb, and causalgia. In these conditions the upper thoracic ganglia can be blocked temporarily with procaine and its effect observed. Occasionally repeated injection of procaine alone is sufficient,[65] but when the pain recurs within a few hours the sympathetic connections must be permanently destroyed. As the effect of this operation is considered fairly surely due to the elimination of vasomotor impulses and not to any interruption of sensory fibers, it is best to perform the preganglionic type of sympathectomy.

The one instance in which actual destruction of the ganglia is obligatory is in dealing with the pain of angina pectoris. Here it is necessary to resect the upper three thoracic ganglia, or to block the ganglia and their rami with procaine and alcohol. The anatomic arrangement of the sensory fibers from the heart is illustrated on the right side of Fig. 269. This illustration shows that it is not necessary to touch the cervical ganglia, as impulses which reach them over the cervical cardiac nerves cannot enter the posterior spinal roots above the highest thoracic segments. (The author is not yet absolutely certain whether painful impulses may not occasionally reach the cord below the third thoracic ganglion, although experience to date has taught him that pathways of cardiac pain traverse only the upper three thoracic ganglia.) As many of these sufferers have advanced coronary disease, open resection can be undertaken in only a relatively small number. To date the author has done upper thoracic ganglionectomies in 10 patients and has relied on alcohol injection in 86 others (see below). With improved technic in intratracheal ether anesthesia and in the operation itself, the author feels that a con-

siderably larger proportion can have the ganglia removed.

The operation is extremely effective in relieving all pain referred to the precor-dium and arm, but it does not affect pain referred to the neck or jaw. This is also not influenced by added resection of the cervical sympathetic trunk, and its path-
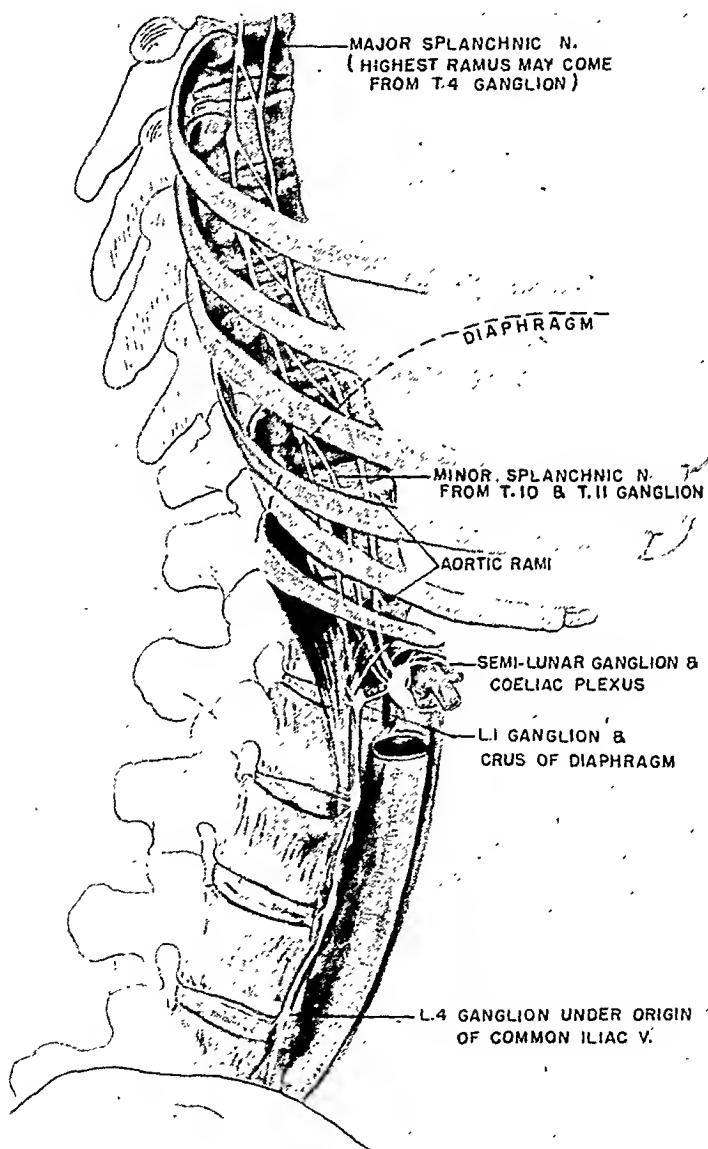


FIG. 280. Thoracolumbar sympathectomy and splanchnicectomy: Relationship of sympathetic chain, splanchnic nerves, and celiac plexus to bony structures, diaphragm, and major blood vessels.

way of transmission is at present unknown. While Ray,[14] Haven and King,[11] and others prefer to interrupt the cardiac sensory fibers by laminectomy and cutting the upper four or five thoracic posterior roots, it is the author's belief that this is a more mutilating and dangerous procedure. It is

## THORACOLUMBAR SYM-PATHECTOMY

The sympathetic outflow to the lower half of the body, including the adrenal glands and kidneys, passes through the lower six to nine thoracic and the upper two lumbar sympathetic ganglia, as shown
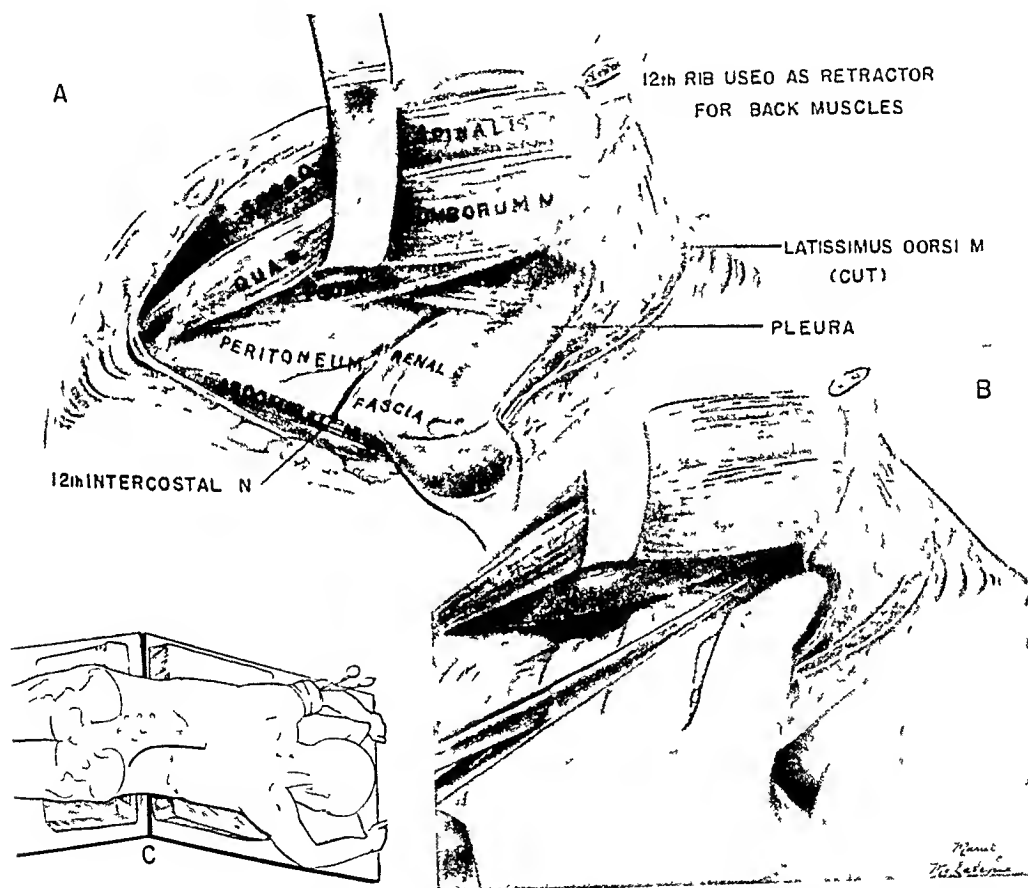


FIG. 281. Thoracolumbar sympathectomy and splanchnicectomy: Removal of twelfth rib (A) and division of central portion of diaphragm (B) Insert (C) shows position of patient on operating table. In (B), vertebral attachments of pleura and peritoneum have been freed. Operator's index finger depresses pleura, while middle finger is inserted into mesial arcade of diaphragm. Fourth and fifth fingers retract renal fascia and peritoneum.

to be recommended only for the neurosurgeon who is well accustomed to spinal operations, but who has not had the necessary technical experience with paravertebral exposure and resection of the ganglia.

in Fig. 269. Many afferent fibers from the abdominal viscera reach the spinal cord over this same network. There is always considerable variation in the arrangement of the more peripheral sympathetic gan-

glia and their rami, and certain anatomic details of importance are not as yet established—viz, the upper limit of origin of the splanchnic rami, as well as the number and importance of the fibers which run from the major splanchnic trunks to the aorta and thence pursue an independent course through the diaphragm

through the eleventh rib recommended by Peet[43] does not permit resection of the upper lumbar ganglia, and therefore fails to denervate the lower extremities or the entire network of rami to the kidneys and adrenal medullas, part of which arises from the chain in or below the diaphragm (Fig. 280). On the other hand, the Adson infra-
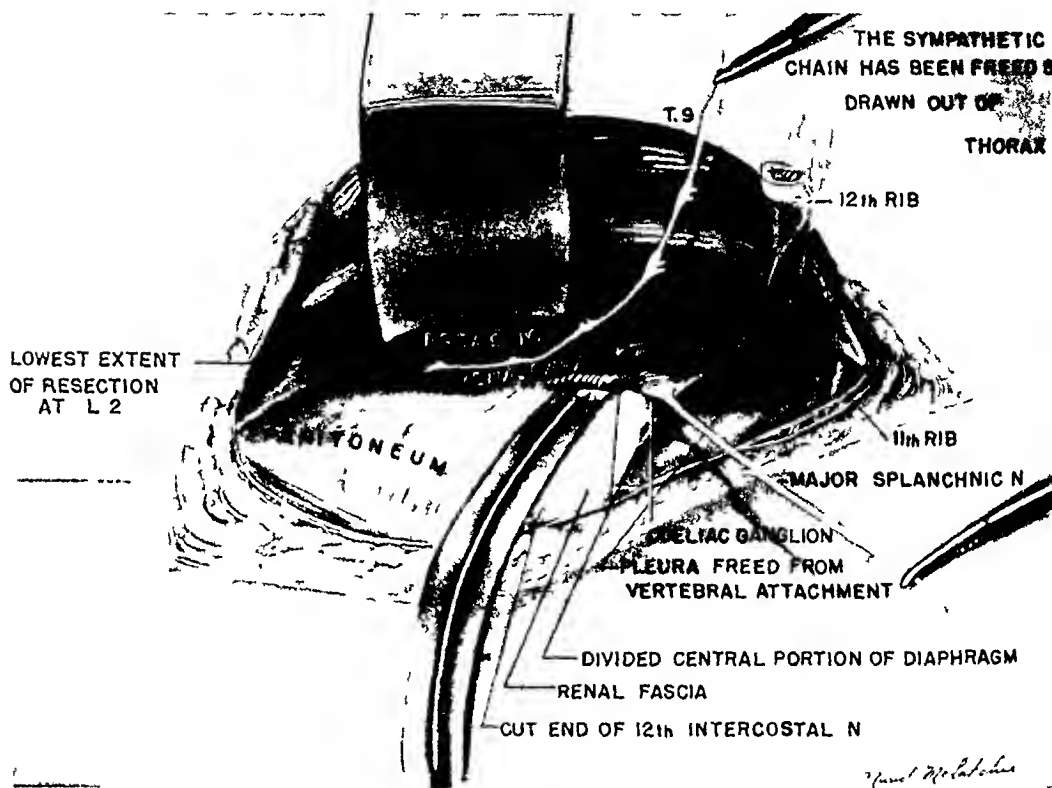


FIG. 282. Thoracolumbar sympathectomy and splanchnicectomy:
(3) Major splanchnic nerve and sympathetic chain have been dissected free and drawn out of thorax. Minor and least splanchnic nerves, whose anatomic connections are quite variable, are not shown.

Experience with the surgical treatment of hypertension has shown that resections limited to either the lower thoracic or upper lumbar ganglia, including the major and minor splanchnic trunks, do not give as effective reduction in blood pressure as the more radical and extensive denervations which have been advocated in recent years. The supradiaphragmatic approach

diaphragmatic operation[4] misses fibers which leave the splanchnic nerves in the thorax and reach the abdominal cavity along the aorta. Furthermore, this infra-diaphragmatic operation permits the removal of only a short length of the splanchnic trunks. These structures carry preganglionic fibers, whose capacity for regeneration has been pointed out above.

This probably explains the experience of de Takáts, Heyer and Keeton,[57] who reported that initial results from the subphrenic operation were encouraging, but short-lived.

Surgeons who undertake the operative treatment of hypertension must always bear in mind the sensitization phenomenon and its clinical implications—that any sympathectomy which is not anatomically complete will be of little value. Even a small minority of intact nerve endings will secrete enough sympathin to diffuse to the denervated neuromuscular junctions on all the neighboring smooth muscle cells and cause their contraction. As spasm of denervated blood vessels is also mediated by adrenaline it is important that all rami to the adrenal medullas be completely interrupted.

The radical thoracolumbar form of sympathectomy recently proposed by Smithwick[51] permits the resection of the paravertebral ganglia from the ninth thoracic down through the second lumbar segments, as well as of the splanchnic trunks from an even higher level down to their termination in the celiac ganglia (Fig. 280). Examination of Fig. 269 will show that this operation gives a complete sympathetic denervation of the lower half of the body* and of the adrenal glands. The possibility of regeneration after extirpation of such an extensive length of ganglionated chain and splanchnic trunks is remote.

In performing this operation intratracheal ether anesthesia should always be used, as insufflation of the lungs is imperative in case of a pleural perforation. The most satisfactory position for the patient on the operating table is shown in Fig. 281, insert. This permits free abdominal breathing, and also flexion at the thoracolumbar junction to flatten the lumbar spine and allow a good view upward into the thoracic cavity, after the twelfth rib has been removed. Lateral supports are in position so that the patient can be rotated away from the surgeon to give a better lateral exposure of the lumbar ganglia.

A paravertebral incision is made 5 cm. lateral to the spinous processes over the two lower ribs and transverse processes of the upper two lumbar vertebrae, then inclined laterally to the crest of the ilium. The medial portion of the latissimus dorsi muscle and the thin fibers of the serratus posterior inferior are cut across above and the lumbar fascia divided below to expose the lateral border of the sacrospinalis muscle, the central portion of the two lower ribs, and the fascial attachment of the abdominal muscles. First the lateral costal attachments of the sacrospinalis are undercut and this muscle retracted toward the midline to expose the central end of the twelfth rib. The rib is next freed of its muscular attachments. It is best to start well laterally near its tip, as this area is not in contact with the pleura. Then the outer free end should be elevated forcibly, cutting its muscular attachments above and below with a scissors, after separating the under surface from the pleura by finger dissection. In this way the rib is cleared centrally and then cut off along with the tip of its transverse process as far centrally as possible. Instead of amputating the rib, the author has often found it convenient to bend it back by forcibly dislocating its vertebral articulations and securing it in this position with a loop of gauze clamped to the drapes, thus obtaining a temporary self-retaining retractor for the sacrospinalis muscle (Fig. 281). After being used in this way the rib should be cut off at the time of closure.

* A few fibers from the upper portion of the major splanchnic trunks to the aorta may be missed, as pointed out above, but their exact origin and physiological importance is as yet uncertain. Should these higher connections turn out to have a significant effect on the maintenance of an elevated pressure, it may be necessary to resect the eighth rib and carry the resection of the major splanchnic nerve to a higher level in certain resistant cases of hypertension.

Once the twelfth rib is out of the way, the key to a wide retropleural and retroperitoneal exposure of the paravertebral gutter is the division of the posterior portion of the diaphragm down to its medial arcuate ligament. To do this, one should start stripping the pleura above from the central portion of the diaphragm and then from the medial portion of the eleventh, tenth, and ninth ribs and the lateral surfaces of the vertebrae. The line of pleural attachment to the diaphragm is easily seen and its separation from the structures enumerated above is best carried out by fingertip dissection. Once it has been widely freed, it is easy to insert the index finger into the medial arcade, where the diaphragm arches over the upper end of the psoas muscle.

Having secured a wide exposure above, the same is done below, cutting through the lumbar fascia between the sacrospinalis and quadratus lumborum muscles mesially and the three layers of abdominal muscles laterally. This brings the surgeon down on the peritoneum, with the twelfth intercostal vessels and nerves running obliquely across the field These structures must be cut, as leaving the nerve intact but stretched is sure to result in a troublesome neuritis. Unfortunately there will be some neuritis, even if the nerve is divided with a minimum of trauma. Then one should develop the peritoneum and renal capsule, with finger and gauze dissection It is best to use a wet handkerchief gauze and the fingers of the left hand to depress the peritoneum and renal capsule ventrally.

A Deaver retractor should be used to catch the quadratus lumborum and then the major psoas muscles as they are exposed The operator is then in position to identify the medial arcade of the diaphragm by slipping a finger into it from below Having done so, he should use the left hand to retract the lateral part of the diaphragm, with the index finger pressing down to the arcuate ligament on one side and the middle finger on the other (Fig. 281 B). It is then a simple matter to cut across the central attachment of the diaphragm with the scissors held in the right hand. Once the muscle has been cut across down through its mesial arcuate ligament, the whole dome of the diaphragm can be displaced several inches laterally. This gives a clear exposure of the major crus with the sympathetic chain and splanchnic nerves lying in full view.

The next step is to proceed with the actual neurectomy (Fig. 282). The major splanchnic is cut off at its insertion in the celiac ganglion and then dissected upward A large brain spoon should be used with an attached small-sized Cameron light on a flexible cord to follow up along the pleural gutter. The tenth rib is about the limit of direct finger dissection, and beyond this the separation of the tissues must be undertaken very gently with a moist cotton pledget on a Hartmann forceps. One must watch out for blood vessels, particularly for vertebral veins which may arch over the sympathetic trunks on the right side and cause dangerous bleeding if torn. Nothing should be cut unless it has been clearly seen and, better still, clamped with a dural clip While making downward traction on the splanchnic trunk the rami connecting it with the sympathetic chain and a few deeper rami to the aorta and esophagus are successively clipped and cut By traction and blunt dissection the limit of safe dissection can usually be carried well above the ninth rib, but when inadequate exposure makes this impossible it is best to remove a portion of the eleventh rib in addition to the twelfth. Often there is a lesser splanchnic trunk which runs roughly parallel to the major one It is resected in the same way.

By the time the splanchnic trunks have been dissected out the more superficial chain of sympathetic ganglia should be

clearly in view as it loops over the heads of the lower ribs. In resecting the chain it is usually easiest to start by elevating the twelfth ganglion on a hook at the level of the severed portion of the diaphragm. One should first work upward, clipping and cutting the connecting rami to the limit of clear visibility. The chain is then divided (as high as its ninth ganglion if possible) and drawn downward (Fig. 282).

The dissection is next carried caudally. As the chain now runs more deeply, shifting its position from the lateral surface of the thoracic to the anterior surface of the lumbar vertebrae, the surgeon can obtain a better view of the region by tilting the table 20 to 30° away from him. The first lumbar ganglion lies at the lateral edge of the crus of the diaphragm, beneath the outer edge of the vena cava on the right and the aorta on the left. The renal vessels usually cross just in front of it. Here again it is important to guard against injury to bridging and underlying blood vessels, particularly veins on the right side, and to cut no rami running into the depths unless they can be clearly seen and clipped. In this fashion the chain can be followed well below its second lumbar ganglion, but as this is the lowest level to receive outgoing vasoconstrictor fibers from the cord there is no reason to follow it farther.

When the entire bed of the incision is dry and it is certain that no gauze has been left behind, closure should be started with careful reconstruction of the diaphragm. Fine silk or cotton should be used for this purpose. If there is an opening in the pleura and air has leaked in, the operator should insert a No. 12 or 14 catheter through the hole and another in the retropleural gutter before proceeding to resuture the lumbar fascia and divided muscle planes. When the muscles have been sutured, air can be aspirated through these catheters as the anesthetist builds up a positive intratracheal pressure to inflate the lung. The catheters are then withdrawn as the subcutaneous fascia and skin are sutured. No drainage is necessary.

Convalescence after the first-stage operation is usually uneventful in the milder group of cases, but may be stormy in the group with advanced disease of the cerebral and coronary arteries. No significant fall in blood pressure persists after the immediate trauma of operation has cleared. At the second stage, however, the fall in blood pressure on sectioning the nerves may be so profound as to require repeated doses of vasoconstrictor drugs for its maintenance at a safe level for the first 12 hours. A good routine practice is to give neosynephrin, 0.2 cc. of a 1 per cent solution, intramuscularly without delay if the blood pressure falls below 90 mm. The dose is repeated at 15 and 30 minutes, and then at half-hourly intervals until a safe level of blood pressure is maintained. Postoperative blood-pressure readings should be taken every half hour during the night after the second operation, and the neosynephrin injection repeated as necessary.

When the patient who has had a radical denervation performed bilaterally first gets up he is likely to have severe postural hypotension. In the thoroughly denervated subject the blood pressure promptly falls to such a low level that syncope soon occurs on standing erect. This tendency to postural hypotension demonstrates the effective loss of vasoconstrictor tone. It can be combated satisfactorily by bandaging the patient's legs from ankle to knee and applying a tight abdominal binder. In a few months compensatory processes occur which make these precautions unnecessary, although many patients find that they must keep moving while on their feet in order to maintain adequate level of blood pressure.

The transitory neuritis which develops along the course of the twelfth thoracic nerve is another cause of minor annoyance

to the average patient. It usually appears within the first few days after operation and subsides in from two to three weeks.

At the Massachusetts General Hospital, where the great majority of these operations have been performed by Doctor Smithwick, the mortality has been 2.8 per cent in a series of over 500 cases. In the early group of favorable cases the operative risk should be almost nil, but in the more advanced cases death occasionally occurs from cerebral thrombosis or cardiac failure.

## APPLICATIONS

This operation was devised primarily to secure a complete denervation of the blood vessels below the diaphragm in the treatment of essential hypertension. For this purpose Smithwick[68] has demonstrated that it is capable of producing a significant reduction in blood pressure in a large proportion (71 per cent) of selected cases of this disease. Many of these patients have now maintained a satisfactory level of blood pressure for periods up to five years. The results appear to be more permanent and, in the severer grades of the disease, far more satisfactory than those after more limited neurectomies above or below the diaphragm. De Takáts, Heyer and Keeton,[57] who have compared the three procedures in an impartial manner, have found that the supradiaphragmatic and infradiaphragmatic sympathectomies gave only temporary results, or none at all; since adopting this combined operation improvement has been achieved, not only in the patients with early and more moderately advanced disease, but also in some in the advanced stage of hypertension with retinal hemorrhages and definite renal damage (de Takáts, personal communication).

The operation is performed bilaterally in two stages ten or more days apart. It is advisable for the beginner, at least, to check the extent of the denervation by postoperative x-rays to show the position of the metal dural clips. In female subjects the resection should always be carried to a point well below the second lumbar ganglia, in order to produce maximum vasodilatation in the lower extremities. In the male, however, it must be borne in mind that if the first and second lumbar ganglia are removed bilaterally the patient will lose the power of ejaculation and therefore be rendered sterile, but not impotent. In the average patient over 40 this does not often matter, but in some of the younger males who plan to have more children, it may be necessary to leave the second lumbar ganglion intact, at least on one side, in order to avoid this complication. A good result can still be nearly always counted on in the more favorable group of hypertensives. In general it is well to remove the nerves on the right first, as this is the more difficult side. Biopsies taken of the twelfth intercostal vessels, a segment of skeletal muscle, and of the renal cortex are of help in grading the degree of vascular and renal damage.

Another use of splanchnic denervation is for cases of intractable upper abdominal pain of visceral origin. White and Smithwick[68] have reported relief of pain in chronic intestinal spasm and hyperirritability, atresia of the common bile duct, metastatic carcinoma of the liver, and penetrating posterior duodenal ulcer with complicating coronary disease by section or alcohol injection of the splanchnic roots. In the two last-named states the poor condition of the patients made surgical denervation impossible, so that the splanchnic rami had to be destroyed by chemical means (paravertebral injection of alcohol from $T_6$ to $T_{12}$).

In case operation is necessary for relief of pain, the surgeon will first have to investigate the pathway of pain transmission by blocking the paravertebral ganglia at different levels with procaine, and in addi-

tion utilize his knowledge of the visceral sensory nerves in order to decide on the extent and type of denervation which will be most effective. An article which deals with this subject has been written by White.[64] In brief, hepatic or biliary pain can be relieved by right splanchnicectomy alone. Under these circumstances the less extensive operation of Peet[43] through the

thalamic tracts (cordotomy) will be necessary to secure relief

## LUMBAR SYMPATHETIC GANGLIONECTOMY

The four lumbar sympathetic ganglia lie on the anterolateral surfaces of the upper four lumbar vertebrae The first is partly hidden by the lateral edge of the major
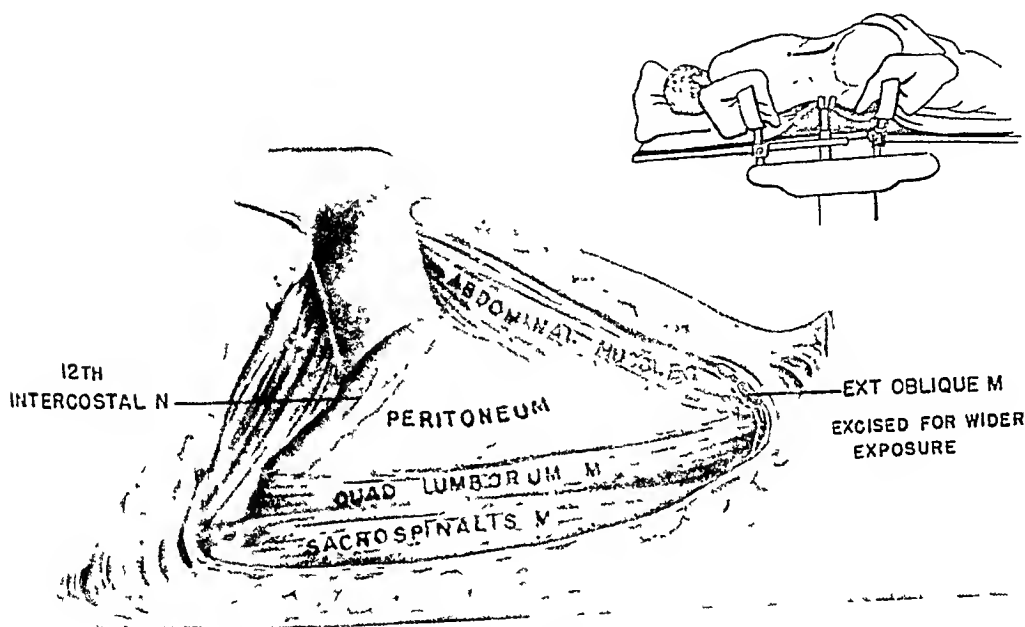


FIG. 283. Lumbar sympathetic ganglionectomy: Position of patient on operating table and incision through lumbodorsal fascia. Patient is on his side, but so secured that table can be rotated back toward surgeon. By elevating kidney bar, space between twelfth rib and iliac crest is increased. It is also important that upper leg be drawn up in order to relax psoas muscle.

eleventh rib gives an adequate exposure for the resection of the major and minor splanchnic trunks. In pain of renal origin the kidney can be desensitized by a dissection of the nerves within its pedicle.[65] Pain from the esophagus, stomach, or bowel is not usually of pure visceral origin, but implies extension of the disease into the posterior thoracic or abdominal walls, regions innervated by the intercostal nerves. Under these circumstances section of the spino-

crus of the diaphragm and the fourth disappears under the common iliac vessels. Over this intervening length the chains lie on the bodies of the vertebrae just medial to the line of attachment of the psoas major muscles, and under the edge of the vena cava on the right and the aorta on the left. A number of lymphatic trunks and nodes surround each chain. One or two vertebral vessels, chiefly veins, may bridge over or run beneath the chains and must

be carefully handled in the course of resection. The important connections of these ganglia with the spinal cord and lumbosacral plexus, as well as the distribution of their pre- and postganglionic neurons, are shown in Fig. 269. It should be emphasized

first the surgical approach followed the technic advocated by Adson and Brown[2]—a transperitoneal approach through a midline abdominal incision, with division of the lateral peritoneal attachments of the cecum or sigmoid, and retraction of the intestines
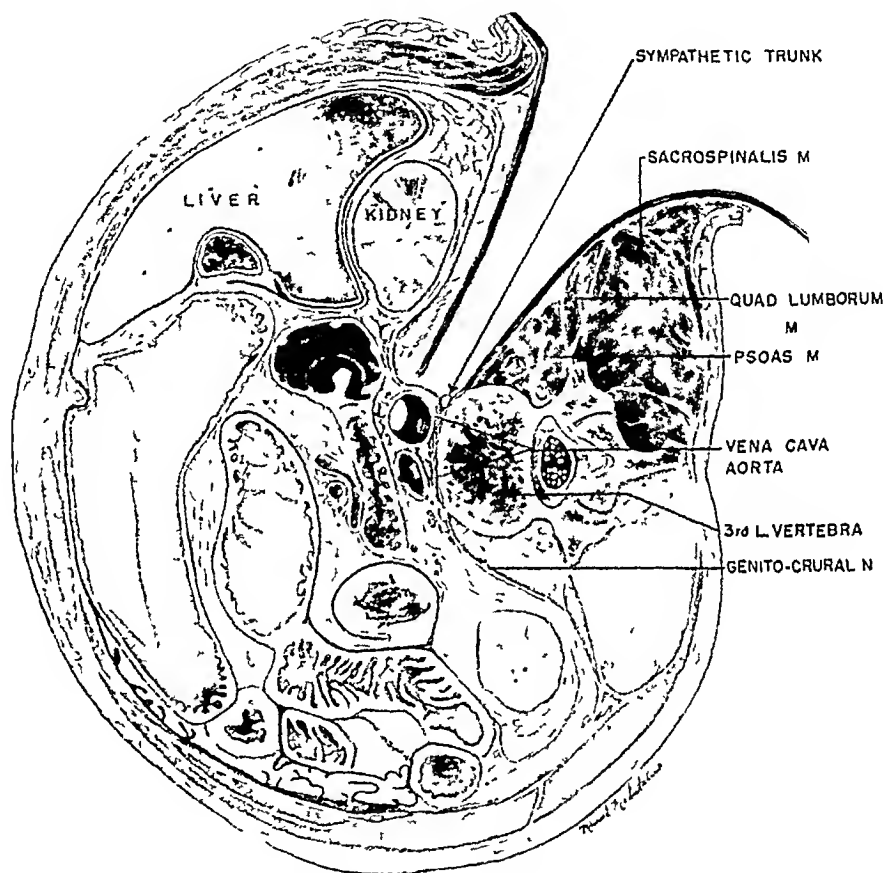


FIG. 284. Lumbar sympathetic ganglionectomy:
Cross-sectional view of exposure.
(Modified from Eycleshymer and Schoemaker: A Cross-Section Anatomy,
New York, D. Appleton-Century Co.)

that the second lumbar ganglia are the lowest to have direct central connections with the cord (white rami communicantes).

Surgical intervention on the lumbar sympathetic ganglia dates from the observation of Royle in 1924,[17] who found an increased circulation of the leg in patients after lumbar ramisectomy for spastic paralysis. At

toward the midline. The transabdominal approach has been replaced in recent years by a variety of retroperitoneal exposures, all of which share the advantages of diminished risk in case of wound sepsis, reduced postoperative distension, and freedom from incisional herniation. The retroperitoneal approach to the paravertebral gutter may

be made through a transverse muscle-splitting incision (Pearl[42]); by an oblique division of the anterior abdominal muscles above Poupart's ligament and the iliac crest (Leriche and Fontaine[30]); or by a paravertebral longitudinal division of the lumbar fascia which unites the sacrospinalis and quadratus lumborum muscles on the medial

to bend the lumbar spin laterally so as to widen the gap between the twelfth rib and the iliac crest, and at the same time to flex the hip and knee of the upper leg in order to relax the psoas muscle and permit its retraction. It is also advantageous to tip the table laterally 30° toward the surgeon as the abdominal muscles and peritoneum
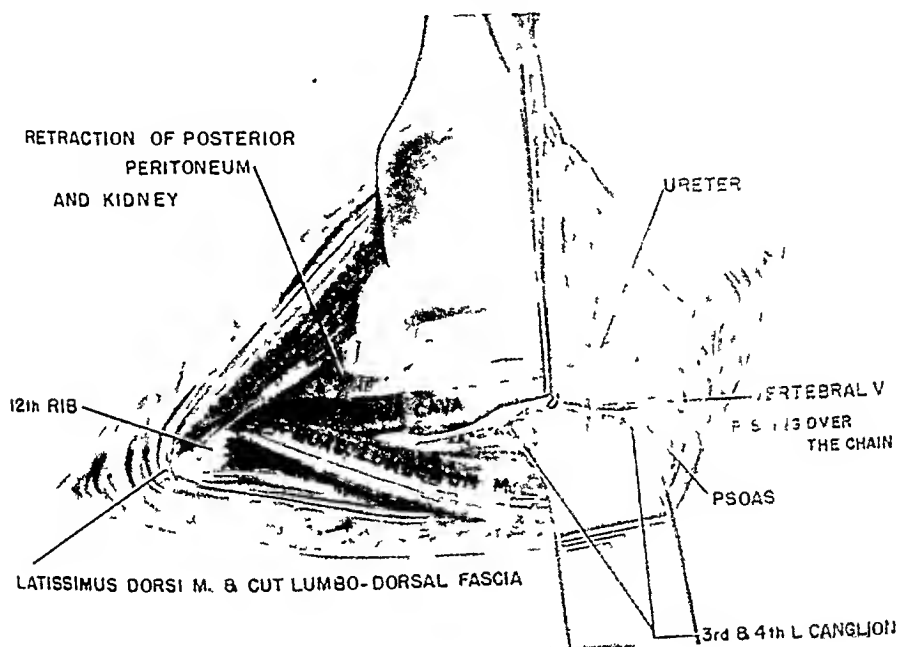


FIG. 285. Lumbar sympathetic ganglionectomy.
Exposure of lumbar ganglia. The third lumbar ganglion usually has a single ramus directed caudally, whereas the second has two rami running dorsally to connect with second lumbar nerve and one running caudally to third. In order to expose first lumbar ganglion it is necessary to follow chain upward to point at which it emerges from beneath crus of diaphragm.

side with the two oblique and the transverse abdominal muscles laterally.

The last-mentioned paravertebral incision is the best for general use, because it parallels the sympathetic trunk and therefore gives the most direct exposure of the lumbar ganglia The operation can be carried out under either a medium high spinal anesthesia or ether. The best position for the patient on the operating table is illustrated in Fig 283, insert. It is imperative

are retracted forward, in order to obtain the best working view of the chain of lumbar ganglia.

The incision should be started 5 cm. lateral to the line of spinous processes and just above the twelfth rib. It is first carried caudally and then laterally for a short distance over the iliac crest. The skin should be cross-marked a number of times in order that opposite points can be approximated accurately in the closure Once the skin

and cutaneous tissues have been divided, it is essential to find the line of fascial attachment between the erector spinae and quadratus lumborum mesially and the abdominal muscles laterally. This is most easily entered in Petit's triangle in the lower part of the incision.

The incision through the lumbar fascia is then carried upward to the under surface of the twelfth rib, dividing a few of the fibers of the latissimus dorsi muscle at its upper end. In case of an unusually fat or short-trunked individual where more room is needed, this can be obtained by dividing some of the external oblique fibers as they insert in the posterior portion of the iliac crest. This exposes the peritoneum with the iliohypogastric and inguinal nerves, which run obliquely down over its posterolateral surface. These nerves should be preserved as the peritoneum is swept off the ventral surface of the quadratus lumborum and psoas muscles. The lateral femoral cutaneous and genitocrural nerves are also exposed and protected as they come into view on the ventral surface of these muscles. Large Deaver retractors should be used over wet gauze to separate the two layers of the incision, particularly in retracting the peritoneum, which will tend to bulge forward unless it is packed back well with handkerchief gauze and a broad, deep retractor (Fig. 284).

In approaching the midline the ureter and its accompanying vessels will be seen adhering to the outer surface of the peritoneum, and finally the aorta or vena cava in contact with the vertebral bodies. The chain of sympathetic ganglia lies on the latter, just medial to the line of attachment of the psoas muscle fibers and in contact with the edge of the aorta or vena cava (Fig. 285). The chain is at times obscured by lymph nodes, but can be easily exposed by blunt dissection and then elevated on a hook. It should be cut off just above the fourth lumbar ganglion, where

it disappears beneath the common iliac vessels. This ganglion is the uppermost one which contains cells of the postganglionic axons to the sciatic nerve, and should be left intact in order to prevent increased sensitization of the denervated arteriolar walls in the foot to circulating sympathomimetic hormones.*

After the chain has been cut between its third and fourth lumbar ganglia, it is an easy matter to follow it upward. The surgeon should grasp the free end of the trunk in a hemostat and use a blunt dissector or a cottonoid pledget in detaching it from the vertebrae. At times the chain is a stout trunk with well-defined ganglia; at others it is a thin nerve without definite ganglionic expansions. In any case it is the only nerve trunk that runs longitudinally along the inner edge of the psoas muscle and attached to the bodies of the vertebrae. The genitocrural nerve must not be mistaken for the sympathetic trunk; this nerve lies on the ventral surface of the psoas muscle about 1 cm. lateral to the chain. Lymph nodes also have been mistaken for ganglia. One should identify the ganglia by their rami communicantes. These connect the ganglia with the spinal nerves, which they reach by running between the mesial fibers of the psoas and the sides of the vertebrae. They emerge from the ganglia at right angles in the case of the second lumbar ganglion, but run obliquely upward from the first and downward from the third. Nothing should be cut that cannot be clearly identified as a ramus and, better still, one should secure all structures with dural clips before they are cut. Bridging vessels, particularly the lumbar veins on

* Ascroft[5] has demonstrated in monkeys that vasodilatation in the lower legs and feet which follows resection of the upper lumbar ganglia is lost if the ganglia over the sacrum are also removed. This is because of the increased sensitization of blood vessels in the feet to circulating sympathomimetic hormones, which occurs whenever a preganglionic denervation is converted into a postganglionic.

the right side, may loop directly over the chain. If cut or torn they retract, causing profuse bleeding which may be most difficult to control.

In case vasomotor and sudomotor paralysis does not have to be carried much above the level of the ankle, as in simple Raynaud's disease, resection of only the second and third lumbar ganglia will suffice, but it is essential that the chain be interrupted above its second lumbar ganglion (Atlas[6]). Whenever it is important to obtain a maximum increase in collateral circulation above the knee, as in cases of thrombo-angiitis obliterans or injury of the main arteries in the upper leg, it is essential to remove the first lumbar ganglion as well. In order to do this it is necessary to obtain the widest possible exposure at the upper end of the incision. In following the chain rostally it will be found to disappear behind the lateral edge of a thin band of fascia and muscle, the crus of the diaphragm. If this is divided upward for about 1 cm., the ganglion is brought clearly into view so that its upper end can be secured with a dural clip and cut. In planning to carry the resection upward to include the upper two lumbar ganglia, it is important to bear in mind that when this is done bilaterally in the male patient the power of ejaculation is lost and he will therefore be rendered sterile. With rare exceptions, neither potency nor the sensation of orgasm is lost.

After resection of the chain, one should make a thorough inspection of the field for bleeding points or any cottonoid pledgets or gauze which may be left behind. When the retractors are removed the peritoneum falls back in contact with the underlying posterior muscles with a minimum of dead space. It is necessary only to bring together the edges of the lumbar fascia between the abdominal and posterior longitudinal muscles with interrupted sutures of fine silk, and then to approximate the fatty subcutaneous tissue and skin. No drainage is required.

### APPLICATIONS

Lumbar sympathetic ganglionectomy is a most valuable procedure for the relief of a number of conditions which lead to spasm of the arteries in the lower extremity. In the ordinary case of Raynaud's disease a resection limited to the second and third ganglia results in permanent cure; patients who had this operation performed at the Massachusetts General Hospital in 1929 still have feet that remain strikingly hot and dry. In thrombo-angiitis obliterans resection of the upper three lumbar sympathetic ganglia should be considered in all younger patients (below 50) when the circulation in the lower leg is seriously impaired, particularly if there is any evidence of neurogenic vasoconstriction or increased sweating. The operation cannot be expected to help when the entire femoral artery has been thrombosed or in the presence of sepsis or extending gangrene. It rarely relieves the pain of open ulceration.

At first it was felt that sympathectomy should be carried out only in patients who had shown a preliminary favorable response after blocking the vasoconstrictor fibers with procaine, or after their inactivation by heating other portions of the body. This preliminary test has been found to be unnecessary and misleading, as in many instances an impressive increase in circulation has developed gradually in spite of the absence of any immediate vasodilatation after spinal or paravertebral block. Lumbar sympathetic denervation has also been distinctly helpful in numerous cases of intermittent claudication, whether associated with Buerger's disease or arteriosclerosis. Here again preliminary procaine block has not been of value in selecting the favorable cases. The results are especially likely to be good when there is evidence of superimposed vasospasm of the extremities

with excessive sweating, and when the arterial obliteration has not involved the femoral artery at the groin.

In arteriosclerotic occlusion of the arteries in the ankle and foot, and particularly when the disease is associated with diabetes, there is rarely a significant amount of vasospasm, so the slight degree of vasodilatation which can be obtained does not often justify the risk of operation.

In traumatic injuries of the iliac, femoral, or popliteal arteries, or when these vessels must be ligated for the resection of an aneurysm or arteriovenous fistula, interruption of the vasoconstrictor fibers may save the limb by dilating the collateral vessels. The importance of this maneuver in war and civilian injuries has been emphasized by Ogilvie,[40] who reports that in wounds of the lower extremity among the soldiers of the British Army in North Africa few extremities survived after popliteal ligation unless vasodilatation of the collateral bed was ensured by ganglionectomy or chemical block. In traumatic wounds ganglionectomy is often out of the question, but much can be done to improve the collateral circulation over the early critical period by paravertebral infiltration of the ganglia and their rami with procaine or alcohol. The technic of these injections is given below. When a critical section of artery must be sacrificed at an elective operation, as in the case of a popliteal aneurysm, the circulation should be safeguarded by a preliminary sympathectomy. Richards and Learmonth[45] have recorded the case of a resection of a popliteal aneurysm with three of the five collateral branches of the artery. Thanks to the preliminary lumbar sympathetic ganglionectomy, the skin temperature of the toes remained at the level of the environment for only five hours and then rose to 92°.

Cases of excessive sweating (hyperhidrosis) may be really incapacitating, from both the inconvenience of constantly wet,

foul-smelling feet and the fungus infections which may develop in the macerated skin. This condition is effectively cured by resection of the second and third lumbar ganglia.

Another use of sympathetic denervation of the lower extremity is for the relief of causalgia, pain in amputation stumps, and the phantom limb phenomenon. This has been discussed by Leriche,[29] Livingston,[32] Homans,[19] and others, whose papers have recently been summarized by White.[65] The physiologic action and use of ganglionic injection or resection in these conditions has already been described above in the section on Thoracic Sympathectomy and need not be repeated here.

A quite different utilization of lumbar sympathetic ganglionectomy is in the treatment of congenital megacolon (Hirschsprung's disease). Sympathetic denervation of the colon was originally advocated by Wade and Royle[60] and is best carried out by bilateral resection of the lumbar chains. A number of successful cases have been recorded in congenital paralysis of the colon in young children, but this procedure has failed consistently to relieve the acquired variety of megacolon which develops in adults after prolonged constipation. Sympathetic denervation of the colon is falling into disuse even in typical Hirschsprung's disease of children, because it has been found that the condition can so often be relieved by the repeated induction of spinal anesthesia (Stabins, Morton and Scott,[55] Telford and Simmons[59]) or by medical treatment with oral doses of mecholyl bromide (acetyl-beta-methylcholine bromide), which was advocated by Law[26] in 1940.

From a surgical viewpoint the lumbar ganglia are not important centers for attack in cases of intractable pain of visceral origin. The reason for this is that the sensory fibers from the biliary system and upper gastro-intestinal tract run through

the splanchnic nerves. Pain from the kidneys can best be dealt with by resecting the plexus of nerves in the renal pedicle, while pain of uterine origin is interrupted by resection of the superior hypogastric plexus.

## RESECTION OF SUPERIOR HYPO-GASTRIC PLEXUS (PRESACRAL NEURECTOMY)

The superior hypogastric plexus is a continuation of the pre-aortic, which origi-

which in turn make up the inferior hypogastric plexuses in the posterior wall of the bladder. Resection of the superior plexus in the interiliac triangle interrupts the sympathetic supply of the pelvic viscera.

Langworthy[24] has recently brought out the fact of fundamental interest that the chief function of the sympathetic motor impulses is to regulate the flow of blood, while visceral activity is largely controlled by the parasympathetic system. This is certainly true of the bladder and uterus,
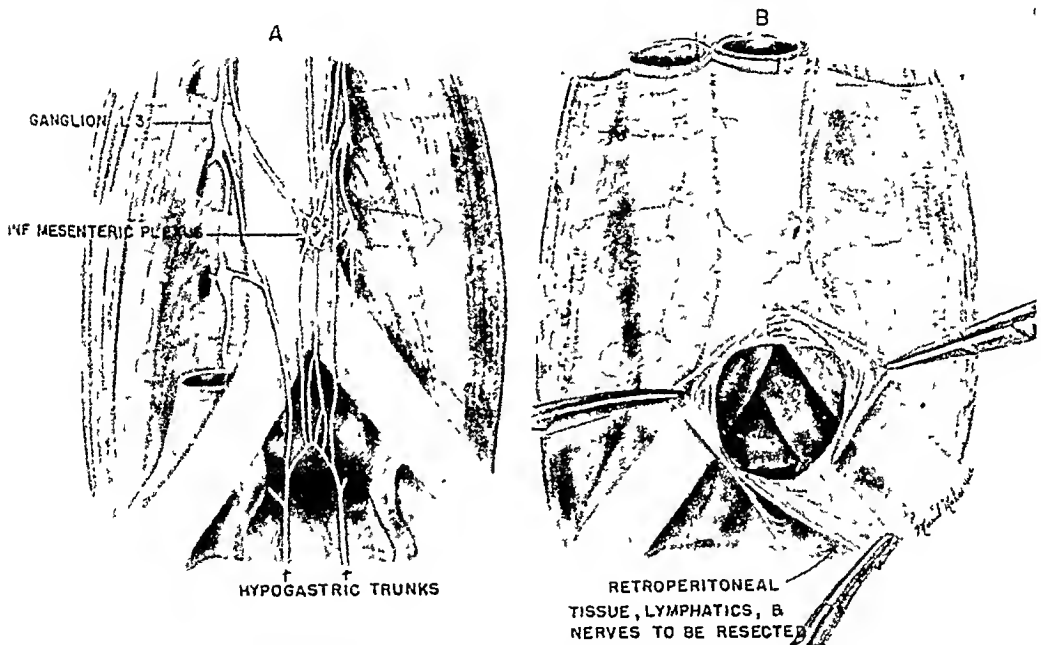


FIG. 286. Resection of superior hypogastric plexus: (A) Anatomic arrangement of plexus; (B) Extent of resection.

nates from the celiac, renal, and upper lumbar ganglia (Fig. 286 A). It is, as its name implies, not a single presacral nerve or even two distinct trunks, but is usually made up of a variable number of delicate fibers (Elaut[9]) which lie in the retroperitoneal areolar tissue in the hollow of the sacrum in the triangle between the common iliac vessels. As the plexus descends its fibers fuse into the two hypogastric nerves,

which undergo no significant change in motor activity following sympathectomy. It is not true of the motor innervation of the vasa deferentia, seminal vesicles, and prostate, which lose the power of persistalsis and ejaculation of sperm. For this reason resection of the plexus will sterilize a male patient, but it will not as a rule make him impotent nor deprive him of the sensation of orgasm. In the female it produces

no detectable alteration in activity of the pelvic viscera, except for an occasional brief episode of uterine bleeding immediately after the operation.

From the standpoint of sensory innervation the presacral fibers transmit the pathways of uterine pain, but do not appear to carry any sensory impulses from the bladder, prostate, or uterine cervix. The latter run with the parasympathetic axons via the pelvic nerves. Painful impulses from the testicle and ovaries run in the spermatic and ovarian plexuses and are likewise not interrupted by presacral neurectomy.

The technic of presacral neurectomy has remained relatively unchanged since it was first described by the French surgeon Cotte.[7] Spinal subarachnoid block is the anesthetic of choice, because it gives such complete relaxation of the abdominal muscles. A left paramedian incision is made, centered on the umbilicus, and carried halfway down to the pubis. The next step is to insert a self-retaining abdominal retractor and tip the table into extreme Trendelenburg position. This simplifies packing the coils of small intestine into the upper abdomen and gives a direct exposure of the aortic bifurcation and promontory of the sacrum. The posterior peritoneum is now divided in the midline to expose the lower end of the aorta and the thin layer of tissue in the hollow of the sacrum between the common iliac vessels down to the level of origin of the hypogastric arteries. The incised edges of the peritoneum should then be grasped with a pair of hemostats and retracted widely, so as to draw the mesosigmoid and superior hemorrhoidal artery out of the way to the left and to give a clear exposure of the common iliac vessels on each side of the field.

Once the peritoneum has been retracted the nerves can be seen in the retroperitoneal network of lymphatics and loose connective tissue, together with a small and inconstant sacral artery and vein. Blunt dissection should be used to free up these structures, care being taken in so doing not to injure the common iliac vein on the left, which lies on the mesial side of the artery and may be partially hidden by the overlying plexus of nerves and lymphatics. It is best to start the neurectomy over the left common iliac artery at the bifurcation of the aorta. At this point the strands of the plexus emerge from under the peritoneum and run down over the vein. The surgeon then picks up the descending fibers on a nerve hook and works across toward the iliac artery on the right, gathering up successive strands of the plexus in so doing. When the entire group of fibers has been gathered up in this way they should be tied off above and cut. By grasping the severed lower stump of the plexus in a hemostat (Fig. 286 B) the whole mass of fibers can be freed caudally by wiping them off the left iliac vein and bony floor of the sacrum with a pledget of moist cotton. Special care should be taken to identify and cut any communicating rami which join the plexus from the fourth lumbar ganglia as they emerge from beneath the iliac vessels.

The dissection should be carried downward along the sacral floor until both common iliac arteries and the vein on the left have been denuded to the point of origin of the internal iliac (hypogastric vessels)—a distance of about 5 cm. The structures in the base of the triangle should then be ligated prior to amputating the entire mass of tissue, in order to prevent seepage of lymph. After this has been accomplished it is necessary only to review the area carefully for undivided strands of nervous tissue before suturing the posterior peritoneum. The table is then flattened, the retaining intestinal packs removed, and the abdominal incision closed in layers.

## APPLICATIONS

The outstanding purpose of resection of the superior hypogastric plexus is for the relief of intractable pain in dysmenorrhea. For the ordinary patient who fails to improve on nonsurgical gynecologic procedures, Meigs[37] recommends that the surgeon should at the same session dilate the cervix, suspend a retroverted uterus, and correct any pathologic process he may find in the tubes and ovaries. He concludes that this operation is the best method of treatment for women with true primary dysmenorrhea, but nevertheless the patients must be selected carefully and the resection of the plexus must be complete. While the resection will interrupt pain from the body of the uterus, it has no effect on pain emanating from the cervix, broad ligaments (which are involved in carcinoma of the uterus), tubes, and ovaries.

Presacral neurectomy has no direct effect on pain from the bladder. It is of no value whatever in carcinoma or in tuberculosis. While occasional successes have been reported in cases of chronic interstitial cystitis (Hunner's ulcer), the abolition of pain is inconsistent and usually incomplete. According to Nesbit and McLellan[39] the benefit does not result from interruption of afferent pathways, but from the reduction of muscular spasm at the bladder neck. A few years ago resection of the hypogastric plexus was frequently advocated for the relief of an atonic bladder. This was based on a misconception that the sympathetic impulses inhibited contraction of the bladder and increased the tone of the internal vesical sphincter. From experiments in animals (Denny-Brown and Robertson,[8] Evans[10]) and clinical observations (McLellan,[36] Langworthy, Kolb and Lewis[25]) it is definitely established that the entire mechanism of bladder filling and emptying is mediated by the sacral segments of the spinal cord. On comparing pre- and post-operative cystometrograms there is no demonstrable difference in the reactions of the smooth muscle in the walls of the bladder nor can the patients detect any alteration in sensation as the bladder becomes distended.

## PERIARTERIAL SYMPATHECTOMY

Periarterial decortication of peripheral arteries was originally advocated by Jaboulay[21] and by Leriche[28] to increase the flow of blood in the peripheral vascular tree and for the relief of certain types of vascular pain. As a result of anatomic and physiologic studies, made in both experimental animals and human patients, it is now generally accepted that neither motor nor sensory axons run for any distance in the walls of the peripheral arteries. Such an arrangement applies only to the large vessels in the thorax and abdomen, where an extensive plexus of nerves runs with the main arterial trunks (pre-aortic, coronary, renal, and mesenteric plexuses). In the arms and legs, however, the sympathetic vasomotor and vascular afferent filaments run in the trunks of the peripheral nerves and are given off to the blood vessels at short intervals. Any periarterial denervation therefore produces degenerative changes in only a short segment of the adventitial plexus.

The mass of data on which these pertinent facts are based has been reviewed in detail by White and Smithwick.[68] No convincing evidence has been published to this date that vasodilatation persists for more than a week after periarterial sympathectomy; furthermore, an equivalent rise in surface temperature may develop for a similar period following any type of operation.[68] This is a nonspecific reaction which takes place as a result of the destruction of living tissue and the absorption of the products of protein decomposition. A more transitory but similar vasodilator response follows the intravenous injection of small

external carotids should be blocked with procaine.

Exposure of the artery is best obtained through an incision along the anterior edge of the sternomastoid muscle centered on the hyoid bone. The muscle and more superficial jugular vein are retracted laterally to expose a considerable length of the ar-

tion tapes. The adventitial coat should be blown off the underlying media by injecting 1 per cent procaine through a fine needle under moderate pressure (Fig. 287, insert A). It is then a simple matter to split the adventitia over the artery with a sharp knife and to dissect it away (Fig. 287, insert B). This is done by grasping
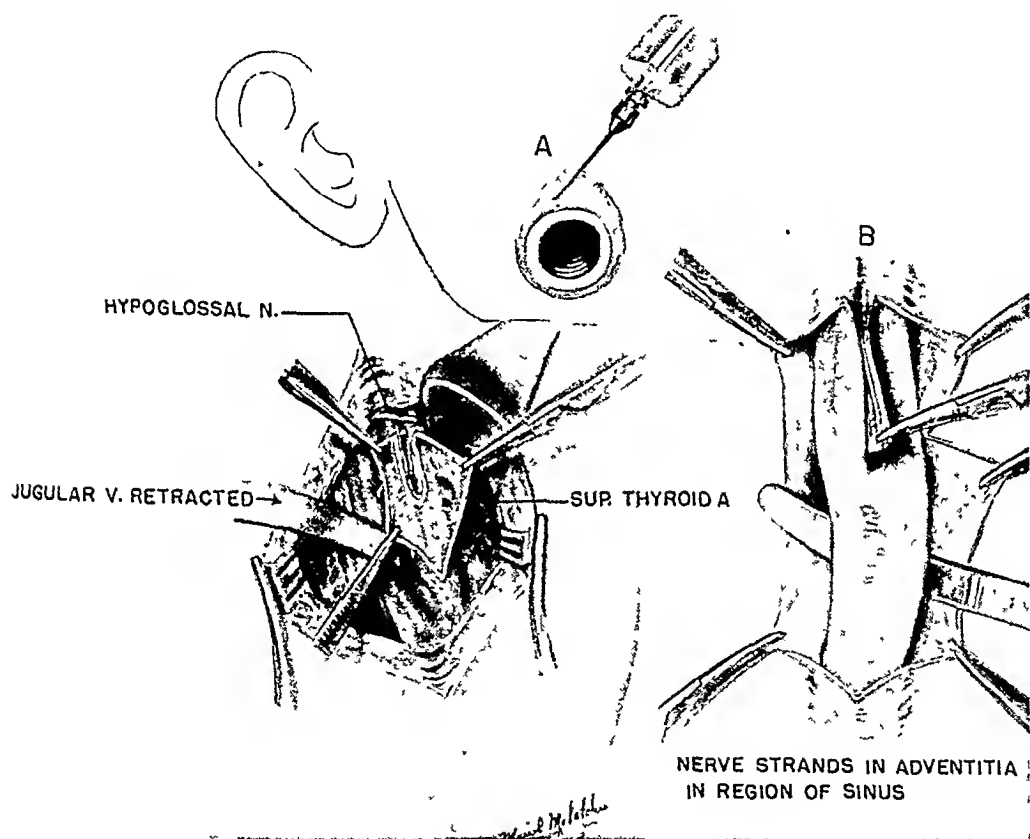


FIG. 287. Denervation of carotid sinus by decortication of common, external, and internal carotid arteries: (A) Separation of adventitia from media by infiltrating procaine solution. (B) After freeing adventitia, carotid plexus of nerves is dissected from region of bifurcation. Special care must be taken not to injure ascending pharyngeal artery, which lies among fibers of plexus.

tery above and below its point of bifurcation.

After entering the carotid sheath, one should free the artery from the underlying vagus and cervical sympathetic nerves, and then lift the vessel from its bed by trac-

the free edge with a number of fine hemostats and using a blunt dissector, or a cottonoid pledget held in a pair of forceps, to wipe the fine outer layer from the dense muscular coat of the artery. The adventitia is adherent only where the plexus of nerves

either the cervical or sacral ganglia and the spinal cord, it is not necessary to attempt injection in these areas, where the insertion of needles would be difficult. In less than a minute 5 cc. of procaine solution will permeate the ganglia when the tip of the needle lies within a centimeter of the sympathetic trunk. When it is less accurately placed the onset of sympathetic paralysis is delayed and larger quantities of procaine may have to be injected. Provided the needle tip lies touching the side of the vertebra and beneath the pleura or peritoneum, failure to secure a satisfactory block is rare.

In order to obtain lasting chemical block the needle must be inserted with the greatest accuracy possible, as alcohol,* owing to its rapid fixation in the tissues, does not diffuse as widely as procaine. Alcohol probably does not completely impregnate the ganglia, but more effectively destroys the delicate white and gray rami communicantes which unite the ganglia with the spinal nerves and visceral plexuses. Because the ganglia and the postganglionic neuron cells which they contain are not completely destroyed,[39] a gradual recovery of vasomotor and sudomotor activity usually takes place. Alcohol injection is therefore not a substitute for ganglionectomy if a permanent release of vasoconstriction or sweating is sought, but it is capable of producing a very effective block for a period of several months. Viscerosensory fibers, on the other hand, appear to have a distinctly lower capacity for recovery, consequently permanent interruption of visceral pain can be achieved by injection.

The risk of infiltrating procaine into the paravertebral area is almost nil, provided it is not injected into a blood vessel or into the subarachnoid space. The situation is different with alcohol, where very severe pain results if there is any seepage into the pleural cavity, and the Brown-Séquard type of paralysis from penetration of the subarachnoid space has been reported in several instances.[41,18] With reasonable care these complications are avoidable, but a postinjection neuralgia is a complaint which occurs with annoying frequency and in spite of all precautions, especially after injection of the upper thoracic ganglia. Here the ganglia lie in such close proximity to the intercostal nerves that it is nearly impossible to secure a chemical destruction of the former without irritating the latter. The patients complain of a burning sensation in the superficial distribution of the involved intercostal nerves, which generally disappears after a few weeks, but in about 10 per cent of cases the neuralgia is severe and at times has persisted for a number of months.

With these dangers in mind, and in view of the low risk of direct surgical attack on the ganglia, their injection with alcohol is recommended only under special circumstances which will be discussed below (see Applications, p. 501). The paravertebral injection of procaine, on the other hand, is so free from disagreeable sequelae that it can be used for diagnosis as well as therapeutic purposes. The neurosurgeon who deals with vascular disease and visceral pain should make a practice of investigating his more obscure cases by preliminary procaine injection to determine the effect of sympathetic block on circulation or pain. Not only will he gain a greater insight into many difficult problems, but he will thereby also become proficient enough to undertake injection with alcohol in those cases where the time factor or the poor condition of the patient makes surgical excision impossible.

The method of inserting the needles for paravertebral block is the same, whether a simple test injection of procaine is to be made or whether this is to be followed by

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* Paravertebral injection of alcohol was first performed for the relief of angina pectoris by Swetlow[56] in 1926.

infiltration of alcohol. In injecting the thoracic ganglia the patient is placed on his side, back and shoulders close to the edge on a small pillow so that the long axis of the vertebral column is straight. When the surgeon is not thoroughly experienced with
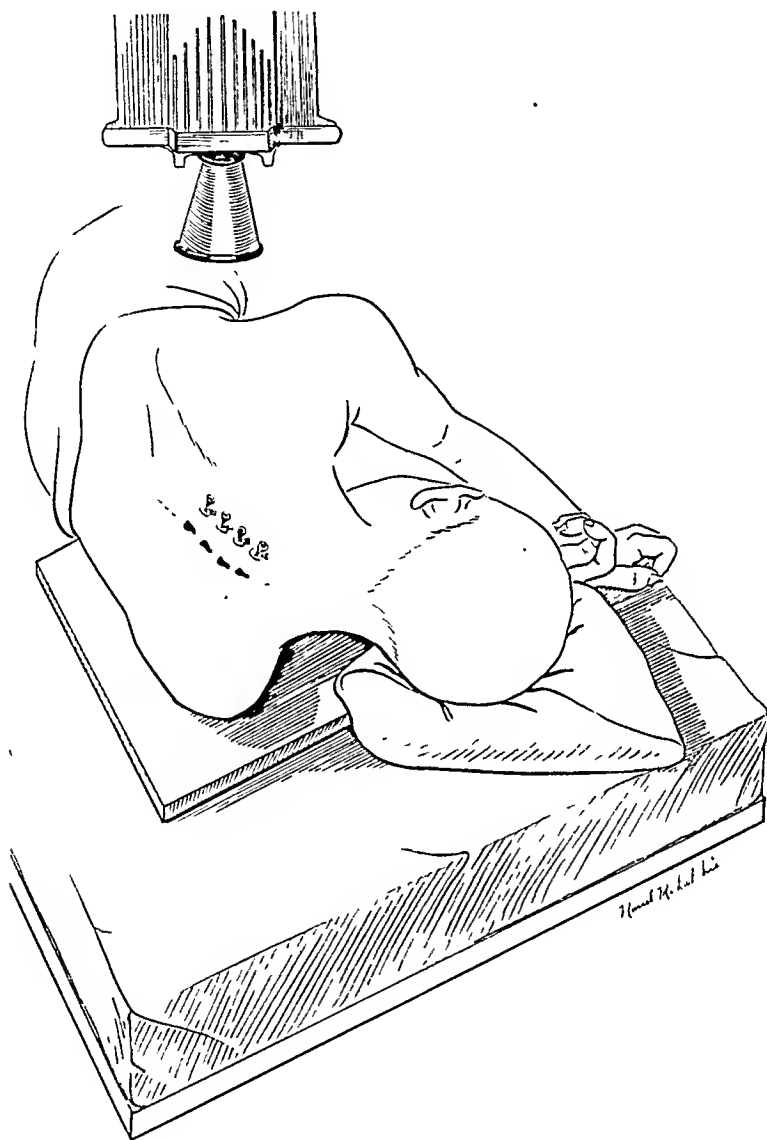


Fig. 288. Paravertebral injection of thoracic sympathetic ganglia: Position of patient and placement of x-ray tube and cassette for checking position of needles.

(Reproduced from article by White and Gentry,[66] Journal of Neurosurgery, 1:40.)

of the bed, legs drawn up, and chin flexed on the chest. The head should be supported the technic, and particularly when needles must be placed with the greatest possible

accuracy prior to a block with alcohol, it is advisable to place an x-ray cassette under the thorax, as illustrated in Fig. 288, so that the exact position of the needles can be determined by x-ray. The technic of roentgenographic control for paravertebral injection has recently been described by White and Gentry.[66]

The bony landmarks for inserting the needles are the spinous processes of the vertebrae. As the thoracic spines are imbricated downward like shingles on a roof,

shafts are pushed through the skin and inserted perpendicularly until their tips touch the bone of the underlying rib or transverse process. This point is reached at an average depth of from 2 to 5 cm., depend'ng on the thickness of the individual back (Fig. 289, first position of needle). It is important to be able to make a rough estimate of the thickness of the patient's back and not to penetrate the pleura in the course of locating the rib and transverse process. If this penetration occurs the
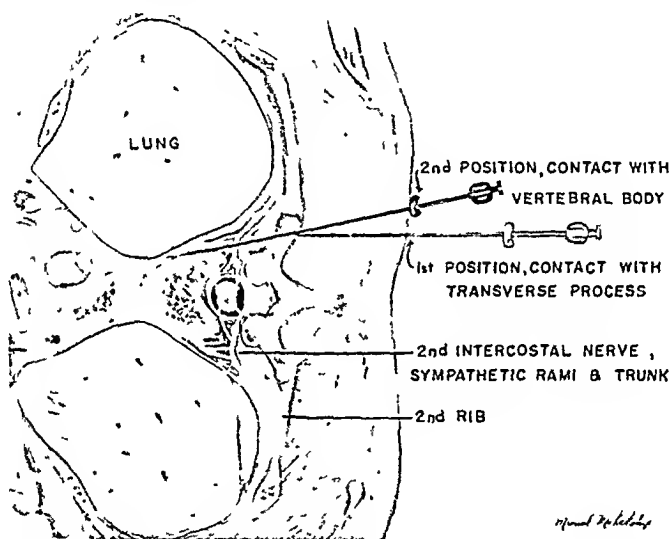


FIG. 289. Paravertebral injection of thoracic sympathetic ganglia:
Method of inserting needles.
(Modified from Eycleshymer and Schoemaker: A Cross-Section Anatomy, New York, D. Appleton-Century Co.)

the tip of any given spine lies over the body of the next caudal vertebra. The points for inserting the needles should be marked 4 cm. lateral to the tips of the appropriate spinous processes. If the skin has been prepared with dilute tincture of iodine, a cotton applicator dipped in acriflavine produces a jet-black sterile mark. After injecting 1 per cent procaine solution intradermally, 10-cm. needles with depth markers (bits of rubber tubing) on their

needle may tear the visceral pleura and underlying alveoli, as a result of which a mild pneumothorax may develop in the course of the next few hours.

Once contact has been made, the tip of the needle should be maneuvered caudally until it can be slipped past the inferior bony edge. The next step is to draw the depth marker out to a distance of 3 cm. from the skin, and then to thrust the needle inward on a bearing at 20° with the

median sagittal plane of the thorax and perpendicular to the surface of the back along its longitudinal axis. When inserted on this bearing the tip of the needle should make a second contact with bone at a further depth of 3 cm. (Fig. 289, second posi-



Fig. 290. X-ray views of needles in position for injection of thoracic sympathetic ganglia and cardiac nerves: (*Top*) Needles parallel, tips in contact with sides of upper four thoracic vertebrae, and inserted to a sufficient depth to reach ganglionated chain. (*Bottom*) Uppermost needle has been pointed too far caudalward, a frequent cause of missing first thoracic sympathetic ganglion and failure to produce a Horner's sign.

(Reproduced from article by White and Gentry,[66] Journal of Neurosurgery, 1:40.)

tion of needle). When no bone is felt at this depth, the needle should be partially withdrawn and directed more toward the midline. On the other hand, when bone is reached too soon, the needle must be re-inserted at a lesser angle until it can be felt slipping along the lateral surface of the vertebra. A useful trick in working the needle inward alongside the vertebra is to start with its beveled tip pointed medially. It will then tend to stick the moment bone is touched, but if rotated 180° so that the beveled tip is turned outward, the needle can often be made to slip forward along the side of the vertebra to the proper depth.

The paravertebral chain of ganglia lies close to the anterior edge of the first thoracic vertebra, and then assumes a slightly more dorsal position on the anterolateral aspect of the other vertebrae above the diaphragm. When alcohol is to be injected, it is of particular importance that the needles be inserted to the actual depth of the chain, a point which can be checked with certainty if a lateral or oblique x-ray is taken (Fig. 290 A). Another point of importance, when accurate injection of the first thoracic ganglion is essential (as in angina pectoris), is to make sure that the uppermost needle is not directed too far caudalward. This mistake is easily made in round-shouldered individuals, with the result that the tip of the first needle may actually come to lie below the second, so that no solution will reach the highest thoracic segment (Fig. 290 B). When this occurs there is no impregnation of the lower portion of the stellate ganglion, and evidence of a successful block, the sign of Horner, will not develop.

When the needles have been inserted so that their tips lie in contact with bone at the sides of the appropriate vertebrae and at the approximate depth of the sympathetic trunk, it is unlikely that any solution can enter the pleural cavity or the subarachnoid space. The solution will enter the retropleural space well anterior to the plane of the intercostal nerves.

Further precautions which safeguard paravertebral injection include the following: never insert the needles attached to the syringe. Occasionally blood or spinal fluid will escape if the needle enters one of the paravertebral vessels or an abnormal prolongation of the subarachnoid space through the intervertebral foramen along an intercostal nerve. Neither of these complications is dangerous if recognized and the position of the needle corrected before injecting procaine or alcohol. It is advisable to inject the solution slowly and to aspirate at frequent intervals to make sure that neither blood nor spinal fluid appears. If any procaine is injected into the pleural space it will set off an immediate cough reflex.

In performing diagnostic blocks with procaine, one should use a 1 per cent solution with adrenaline and inject 5 cc. through each needle. If signs of sympathetic paralysis do not appear within 5 to 10 minutes this dose may be repeated, but in the event of a second failure it is best to check the position of the needles with a portable x-ray taken in the oblique position, as described above.

When a lasting block is to be made with alcohol the needles must be placed with far greater accuracy, due to the limited diffusibility of this substance, which is rapidly fixed by protoplasm. The author formerly relied on a preliminary injection of procaine to demonstrate the proximity of the needles to the sympathetic trunk.[63] If 2.5 cc. of 2 per cent procaine instilled through each needle failed to produce clear-cut evidence of nerve block (anesthesia of the upper thoracic dermatomes, a hot dry hand, and a Horner's sign), the needles were withdrawn to be reinserted at a later date.

Since development of the technic of x-ray localization (White and Gentry[66]),

the insertion of the needles can be so accurately controlled that failure to obtain a rapid and satisfactory block is rare. When it is clear that the needles have been correctly placed and that the preliminary injection of small quantities of 2 per cent procaine has produced no anesthesia of the ulnar nerve (a complication which may occur if the uppermost needle is inserted above the first rib) or evidence of subarachnoid block, it is advisable to inject an additional 3 cc. of 1 per cent procaine so-

any pain, one should stop at once until it subsides. Before withdrawing the needles, there should be injected 0.25 cc. of lipiodol, or, better still, the new Cavitrast contrast medium (prepared by the Eastman Kodak Company), which is rapidly absorbed in the tissues. Subsequent anteroposterior and lateral x-rays will map out the area of infiltration, a point of great value in developing the technical skill of the surgeon and in detecting the cause of failures.

When paravertebral injection of either
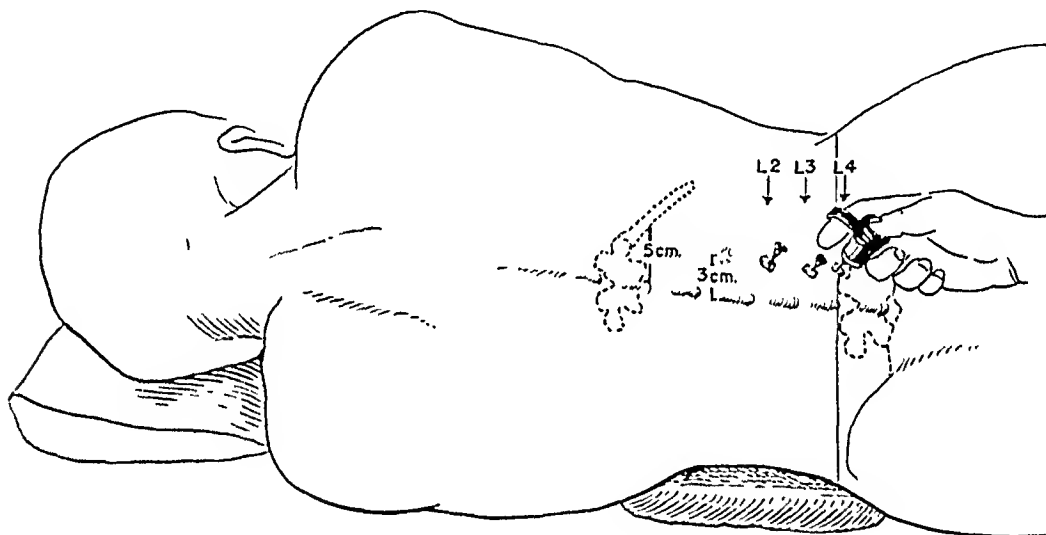
Fig. 291. Paravertebral injection of lumbar sympathetic ganglia:
Bony landmarks for inserting needles.
(Modified from White and Smithwick, The Autonomic Nervous System, New York, Macmillan.)

lution. This will ensure a thorough procainization of the paravertebral nerves so that the infiltration of alcohol will not be painful.

The actual injection of alcohol is performed slowly, extreme care being used not to shift the tip of the needles from contact with bone and to aspirate at frequent intervals for blood or spinal fluid. The instillation of 5 cc. of 95 per cent alcohol through each needle should consume several minutes. If the patient complains of

procaine or alcohol is to be carried out in the lumbar region, the same general directions and precautions apply that have been outlined above. The injection is most conveniently performed with the patient lying in the lateral position (Fig. 291). The points for inserting the needles should be marked 3 cm. lateral to the upper edge of the lumbar spines and cutaneous wheals should be raised with 1 per cent procaine.

Next, 10-cm. needles equipped with depth markers are thrust through these

wheals and pushed inward perpendicular to the plane of the back. They should make contact with the transverse processes of the corresponding vertebrae at a depth of from 3 to 6 cm, according to the muscular development or obesity of the individual. If immediate contact is not made with bone, there is no risk of penetrating the peritoneum, because of the interposed belly of the psoas muscle.

route in connecting the lumbar nerves with the ganglionated chains. If each needle is slid well forward on the lateral surface of the vertebra, its tip will penetrate close to the anterior edge of the psoas muscle. Procaine or alcohol reaching this level can be counted on to infiltrate the retroperitoneal tissue at the edge of the aorta and vena cava and to bathe the sympathetic trunk with little, if any, infiltration of the
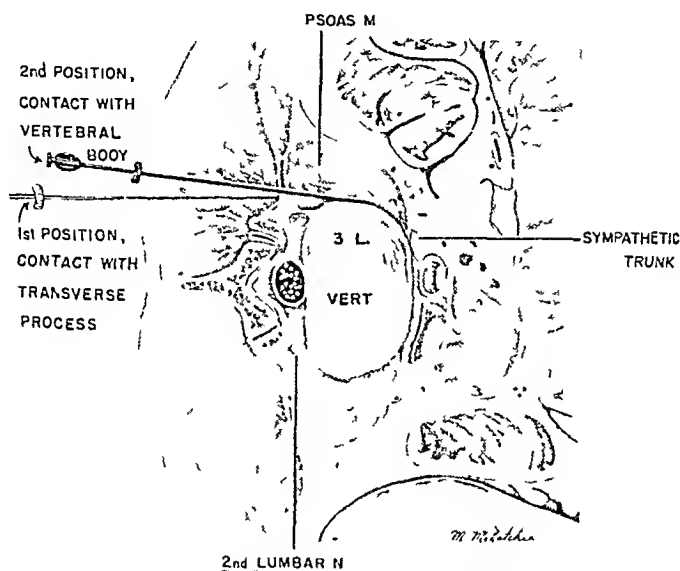


FIG. 292. Paravertebral injection of lumbar sympathetic ganglia:
Technic of inserting needles.
(Modified from Eycleshymer and Schoemaker, A Cross-Section Anatomy, New York, D. Appleton-Century Co.)

Once the transverse processes have been located, the depth markers are set to measure an added depth of 4 cm. Each needle is then pointed slightly upward, to pass above the edge of the transverse process, and slightly toward the midline. Contact should be sought with the side of the vertebra at the added depth marked on the shaft. In carrying out this maneuver the tip of the needle scrapes along the side of the vertebra and is protected by the overlying belly of the psoas muscle (Fig. 292). The sympathetic rami follow this same

lumbar plexus of spinal nerves, which lies in a more dorsal plane of the psoas muscle (Fig. 292). As in the case of paravertebral injection of the thoracic ganglia, it is important to make certain that none of the needles has penetrated a blood vessel or the subarachnoid space.

In carrying out a temporary block with procaine, one should inject 5 to 10 cc of a 1 per cent procaine-adrenaline solution through each needle. This should give rapid warming and drying of the lower leg and foot, with a variable degree of anes-

thesia over the lumbar dermatomes and at times loss of motor power in the iliopsoas, obturator, and quadriceps femoris groups of muscles. When alcohol is to be injected, one should make a preliminary injection with a minimal amount of procaine (2 to 2.5 cc. of 2 per cent solution) to test the

can be avoided by using radiographic control in inserting the needles (Fig. 293). Once it has been ascertained that the needles are correctly placed, it is best to increase the amount of procaine injected to a total of 5 cc., in order to ensure thorough anesthesia before alcohol is in-



FIG. 293. Paravertebral injection of lumbar sympathetic ganglia:
Lateral x-ray taken after insertion of needles. Opaque medium (Cavitrast) has been used to show dispersion of injected solution.

proximity of the needles to the sympathetic trunk, just as described above for alcohol injection in angina pectoris If clear-cut signs of sympathetic paralysis fail to appear within ten minutes, the needle must be withdrawn and the procedure repeated at a later date. Such failures

troduced. Five cc. of 95 per cent alcohol is then infiltrated slowly through each needle.

Whenever alcohol is injected, for blocking either the thoracic or the lumbar ganglia, it is best to perform the injection with the patient in his bed, and then to keep

him in approximately the same position for at least an hour with a minimum of muscular movement. Gross movement, such as shifting the patient from an operating or x-ray table to his bed, may cause wide diffusion of the alcohol beyond the area of procaine anesthesia and thereby result in severe pain. There is, however, no need to keep the patient immobilized once the alcohol has become fixed in the tissues, so that he may be permitted to turn in bed after an hour, and, if his general condition permits, he can usually be up and about on the following day.

### Applications*

Paravertebral procaine block is undoubtedly the most effective diagnostic test for predicting the increase in circulation that can be achieved following sympathetic denervation of the arterial tree to the arm or leg. It is also a most valuable aid in the study of visceral pain. In many obscure cases, such as the pain of aortic aneurysm (White[62]) the sensory pathways have been mapped out by this method and, as a result, lasting relief secured by their subsequent permanent interruption— a much less mutilating and less dangerous method than posterior root section or cordotomy. It has also been possible to secure temporary sympathetic motor denervation of various viscera to see what effect sympathectomy might have. By this means a number of cases of intractable paroxysmal tachycardia have been restored to normal rhythm.[63]

Even temporary blocking of the visceral nerves may result in permanent relief of a number of painful states. This is particularly true of cases of minor causalgia and traumatic arthritis, where a single injection of procaine may give relief lasting for

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* For a complete review and bibliography of this subject, which is far too long to cover in this chapter, the reader is referred to the monograph on the autonomic nervous system by White and Smithwick.[64]

days. After repetition one or more times, permanent relief has often been reported. On the other hand, when pain recurs as the procaine is absorbed, there is good evidence that lasting benefit will follow either a permanent block with alcohol or resection of the appropriate sympathetic trunks.

Alcoholic injection has been found to be of particular value in patients with severe coronary disease and angina pectoris, painful aneurysms of the aortic arch, and certain other types of visceral pain where the poor condition of the patient renders surgical denervation unsafe. For the patient who can tolerate a sympathetic trunk resection, however, this is unquestionably the procedure of choice. Paravertebral injection is again a valuable substitute in patients with sudden occlusion of a vital artery from embolism or trauma, when it is necessary to increase collateral circulation at once in order to preserve the vitality of the limb. Under these circumstances there may not be sufficient time to permit a sympathectomy, even if the patient's condition should permit. Vasodilatation must then be obtained either by alcohol or repeated injections of procaine.

Aside from these special instances, it is always better to resect the necessary sympathetic structures. Alcohol injections may fail even in the most experienced hands and may also produce an annoying neuralgia, whereas surgical resection (except in the poorest risk cases) carries a remarkably low operative mortality and causes no subsequent inconvenience to the patient, except for the dry skin which follows sudomotor paralysis.

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SECTION SEVEN

# CHEMOTHERAPY

# 20

# Chemotherapy in Neurosurgery

## Cobb Pilcher, M.D.

The introduction of the sulfonamides, whose uses and value were demonstrated with ever-increasing impetus during the 1930's, brought to neurosurgery, as to other therapeutic fields, a revolution in the therapy of infectious conditions. New drugs have succeeded each other with great rapidity and the re-discovery* of the antibacterial qualities of penicillin by Florey[1,3,5] has added a new and startling chemotherapeutic agent to the armamentarium of the physician. No one can gainsay the stimulus of scientific investigation induced by wartime necessity and opportunity as a factor in the rapid increase in knowledge, nor can anyone predict the possible advances in the immediate future of chemotherapy.

For these reasons, this chapter can do little more than to afford a temporary picture of the changing panorama of chemotherapy. Such a picture should be of some value, however, since some fundamental principles are well established and some taboos clearly delineated.

## THE SULFONAMIDES AND THE NERVOUS SYSTEM

The value of the sulfonamides—especially sulfanilamide, sulfadiazine, and sulfathiazole—when administered systemi-

cally is clearly established in the treatment of most of the so-called "pyogenic" infections. Such infections of the nervous system, however, present a separate problem, since these drugs pass into the cerebrospinal fluid in varying concentrations, usually much lower than the prevailing blood level. Thus sulfathiazole rarely, if ever, reaches a significant therapeutic concentration in the cerebrospinal fluid. Sulfanilamide and sulfadiazine may, on the other hand, attain satisfactory concentration if the blood level is high. Because it is effective against a greater variety of pathogenic organisms and because it may be maintained at a higher blood level, sulfadiazine is the preferable sulfonamide for systemic administration. Its effectiveness against infections of the nervous system seems to be dependent upon and proportional to a high blood level (preferably 20 to 30 mg. per cent).

It would seem desirable to place the sulfonamides in more direct apposition to the site of infection, but this concept introduces new problems. Because of their high alkalinity, solutions of the sodium salts of the drugs are highly irritating to the brain and spinal cord and should never be injected intrathecally. Similarly, microcrystalline suspensions of the sulfonamides are valueless or actually harmful when placed in the cerebrospinal fluid.[5]

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* The antibacterial action of penicillin was first noted by Fleming[4] in 1929.

When applied directly to the brain, the sulfonamides produce marked reactive changes in all of the cellular elements of the brain and its coverings.[7] These changes are least marked with sulfanilamide and most marked with sulfathiazole. In addition to these morphologic reactions, sulfathiazole may produce violent convulsions when applied to the intact cortex[7,13] (or even when applied extradurally, if there is an opening in the dura). For these reasons sulfathiazole should never be applied topically to the central nervous system and sulfanilamide is preferable to sulfadiazine for such local therapy. Furthermore, since the irritative reactions are roughly proportional to the amount of the drug employed, minimal dosage should be used.

Whenever the sulfonamides are administered, systemically or locally or both, the blood level must be frequently determined and used as the criterion upon which dosage is based. The urine should be examined daily for concentrations of drug crystals or erythrocytes. Persistent fever, not justified by the patient's infection, may be due to the drug, and this fact should be constantly kept in mind.

## PENICILLIN AND THE CENTRAL NERVOUS SYSTEM

The time is not yet ripe for final comparison of the value of the sulfonamides with that of penicillin. For some purposes, however, the advantages of penicillin are well established.

Even with very large dosage, penicillin administered intravenously or intramuscularly is nontoxic. Its ready solubility permits high concentration in doses of small volume, but its rapid excretion requires frequent (or continuous) administration. For the latter reason, intramuscular injection, with its more gradual absorption into the blood stream, is preferable to intermittent intravenous administration.

When injected intrathecally in small doses, penicillin is mildly irritating, but produces no permanent ill effects.[9,11] However, Walker[12] has recently shown that large amounts of penicillin injected into the ventricles, into the cortical tissue, or into the cisterna magna may produce convulsive seizures. These observations have been confirmed in the author's laboratory (to be published). It should be remembered that a rather marked pleiocytosis in the cerebrospinal fluid may be produced by the drug and this finding should not be erroneously attributed to the infectious process which is the object of treatment.[*]

Even with high intravenous dosage, penicillin does not appear in the cerebrospinal fluid in significant concentration.[11] For this reason, injection intrathecally, into the ventricle or into the locus of infection itself (or a combination of these methods), is essential in the treatment of infections of the central nervous system.

The value of the local use of penicillin in wounds is not yet established and the sulfonamides are, at present, preferable for this purpose.

As regards its antibacterial properties, the range of the therapeutic effectiveness of penicillin is very much the same as that of the sulfonamides, but penicillin is distinctly more useful in staphylococcal infections.[9]

The limitations of chemotherapeutic agents must be clearly recognized. From the neurosurgical point of view their great value lies in treatment of the "pyogenic" infections due, for the most part, to the hemolytic streptococcus, the hemolytic *Staphylococcus aureus,* and the pneumococcus. The value of penicillin in treatment of syphilitic and certain other infections is of equal importance in other fields of medicine.

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[*] This irritative effect probably is due to some extent to impurities, and varies in different preparations of penicillin.

## TREATMENT OF INFECTIONS AND WOUNDS OF NERVOUS SYSTEM

Pyogenic Meningitis. This occurs not only as a primary blood-borne infection, but it may be secondary to mastoiditis, sinusitis, osteomyelitis of the skull, brain abscess, or contamination of traumatic or surgical craniocerebral or spinal wounds.

Since it can be given directly into the cerebrospinal fluid, penicillin is the drug of choice. It should not be forgotten, however, that severe meningitis is a potential and likely source of blood-stream infection. Hence, systemic medication should not be neglected.[10] Penicillin should be administered by lumbar puncture in doses of 15,000 units twice daily, and by intramuscular injections, 25,000 units, every three hours.

More heroic therapy is necessary at times. If the lumbar puncture elicits only thick exudate, the penicillin should be injected directly into the cisterna magna. If there is reason to suspect cerebrospinal-fluid blockage at the outlet of the fourth ventricle, with internal hydrocephalus, penicillin should be injected into a lateral ventricle in addition to the lumbar route. To do this, the surgeon must provide a suitable burr hole (see Chapter 1), and 10,000 units, injected twice daily, will be adequate.

If circumstances permit, a continuous intravenous drip of penicillin (in saline solution), regulated to deliver approximately 25,000 units every four hours, may be substituted for the intramuscular injections and will maintain a more constant level of the drug in the blood.

If penicillin is not available, sulfadiazine should be given by mouth (or its sodium salt intravenously) in sufficient dosage to maintain a blood level of 20 to 30 mg. per cent.

Brain Abscess. For chemotherapy, brain abscess presents the most difficult problem in the nervous system. Drugs administered systemically, or into the cerebrospinal fluid, do not penetrate the protective capsule and gain access to the infecting organisms. There is some evidence that injection of penicillin directly into an abscess cavity, after aspiration of its purulent content, may result in healing, without resort to more radical surgical drainage. At present, however, evidence is not sufficiently convincing to justify final conclusions and accepted surgical methods must be preferred (see Chapter 4).

This does not mean, however, that chemotherapy has no place in the treatment of brain abscess. Meningitis is an ever-present threat, particularly after surgical penetration of the protecting capsule. Vigorous chemotherapy should be employed, as outlined for the treatment of meningitis, except that intrathecal medication may be postponed if no evidence of meningeal irritation is present.

Traumatic Craniocerebral and Spinal Wounds. Whether civil or military, traumatic craniocerebral and spinal wounds present a fertile field for chemotherapeutic methods. So great is their value and so striking the results of their use that the surgeon is tempted to neglect or shorten the employment of recognized surgical methods. The author wishes strongly to emphasize that *there is no short-cut to good surgery,* and that chemotherapeutic agents, valuable as they are, do not constitute a substitute for the sound principles of the surgical treatment of wounds of the nervous system. Early operation, thorough cleansing of the wound, careful débridement, removal of accessible foreign bodies, meticulous closure, and suitable drainage must never be neglected.

These statements do not for a moment obviate the facts that, when early operation is impossible, chemotherapy may be life-saving, and that the incidence of in-

fection in all such wounds may be greatly reduced by its use.[2]

In all traumatic wounds in which the brain or spinal cord is exposed (and probably in more superficial wounds as well), sulfanilamide is the drug of choice for local application. No wound should be "packed" with any drug, but sulfanilamide should be "dusted" in until a thin, evenly distributed layer of the drug can be seen.

If the wound is seen early and no obvious infection is present, sulfadiazine should be given orally (or intravenously, if the patient is unconscious) at the earliest possible moment, and continued until danger of infection is past.

If infection has already developed, penicillin should be given systemically and intrathecally, as already described.

Wounds Involving Peripheral Nerves. These wounds involve evidence that is as yet contradictory regarding the effects of the sulfonamides upon the regeneration of sutured nerves. For this reason, if the wound is seen early and nerve suture, as well as complete cleansing and débridement, is possible at this time, no drug should be employed locally. On the other hand, late or obviously infected wounds, or those in which nerve suture is not feasible at the time of primary closure, should be "dusted" with sulfanilamide. Systemic chemotherapy should be employed, prophylactically or therapeutically, as already outlined, in all cases.

Clean Surgical Wounds. In the author's opinion, clean surgical wounds require no chemotherapy. To place an irritating substance in a wound which should be completely aseptic is not compatible with the principles of good surgery and should be entirely unnecessary as well.

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Vs. means "differential diagnosis from."